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SYSTEM

OF

CHEMISTRY.

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A

SYSTEM

OF

CHEMISTRY.

IN FOUR VOLUMES.

BY THOMAS THOMSON, M.D.

LECTURER ON CHEMISTRY IN EDINBURGH.

THE SECOND EDITION.

VOL. III.

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DIVISION II. OF BOOK II. CONTINUED.

GENUS VI. SALTS OF IRON.

Chap. III.

THE compounds which the acids form with the oxides of iron were formerly distinguished in chemistry by the epithet *martial*, because Mars was the title given by the alchymists to iron. The most important of these salts have been long known. No metal attracts oxygen and combines with acids with more facility than iron; many of its salts therefore are found ready formed, or at least are often formed during the multiplicity of operations to which this very useful metal is exposed. Some of these salts have been long of great importance in manufactures. They form the basis of writing ink and of the black dye, and are employed also to communicate several other colours to cloth.

Book II. Division II.

Iron is capable of combining with two doses of oxygen, and several of the acids unite with each of its oxides. There are therefore two sets of salts which have iron for their bases; one set containing the black oxide, the other the red. The last of these sets was scarcely attended to by chemists till Mr Proust published his *Researches on Prussian Blue* in 1797; in which he described the properties of the salt composed of the red oxide of iron and sulphuric acid; which, according to the rule formerly laid down, I shall call *oxysulphat of iron*. Since that time Mr Davy has ascertained the existence of several more of these salts.

The salts of iron may be distinguished by the following properties:

Characters. 1. The greater number are soluble in water; and in general the solution has a greenish or yellowish red colour, and an astringent taste.

2. The triple prussiats occasion in these solutions a precipitate of a deep blue, or at least which acquires that colour on exposure to the atmosphere.

3. Hydrosulphuret of potass occasions a black precipitate.

4. Sulphureted hydrogen renders the solution nearly colourless. but occasions no precipitate *.

5. Gallic acid, or the infusion of nutgalls, occasions a black or purple precipitate, at least if the solution has been for some time exposed to the air.

---

* From this rule the oxygenized salts of iron must be excepted. In them sulphureted hydrogen occasions a precipitate. This precipitate is sulphur, thrown down by the decomposition of the sulphureted hydrogen; at the same time the salt loses a portion of its oxygen.

I. Detonating Salts. Chap. III.

Sp. 1. *Nitrated Iron.*

Nitric acid, when as strongly concentrated as possible, does not act rapidly on iron; but when the acid is of moderate strength, the action is very violent, a prodigious torrent of gas is extricated, which Dr Priestley found to be a mixture of nitrous oxide and nitric oxide. During this action the iron is oxidized to a maximum, and a red powder precipitates, consisting probably of oxynitrat with excess of base. These phenomena have been long known; but it was not till after Mr Proust's *Researches on the Prussiats of Iron* that the existence of two salts consisting of this acid, combined with each of the oxides of iron, was well understood by chemists. It is the *oxynitrat* of iron which is obtained by the usual process. Mr Proust merely announced the existence of the simple nitrat, but it has since been examined by Mr Davy.

1. *Nitrat of Iron.*—When nitric acid of the specific gravity 1.16 is poured upon iron, it acts upon the metal but slowly, no gas being given out for some time. The solution becomes of a dark olive brown in consequence of the nitrous gas which it holds in solution; but when exposed to the air, it becomes pale, because that gas combines with oxygen and is converted into nitric acid. When alkalies are poured into it, a pale green precipitate falls, consisting of iron oxidized to a minimum. This solution absorbs nitrous gas. It cannot be concentrated, nor even heated, without being converted into oxynitrat*. Formation.

* Davy's *Researches*, p. 187.

Book II. Division II.

2. *Oxynitrat of Iron.*—This is the salt obtained when iron is treated with strong nitric acid, or when the nitrat is heated or left exposed to the air. The solution is of a brown colour, and does not yield crystals. When evaporated, it lets fall a red powder, not afterwards soluble in nitric acid; and sometimes when concentrated assumes the form of a jelly. When strongly heated, the acid is disengaged, and the oxide remains in the form of a fine red powder. Hence solution in nitric acid, evaporating to dryness, and digesting the residuum in water, is the method recommended by Bergman, and formerly practised by chemists to separate iron from earths. The iron and earths are first dissolved together in nitric acid; by the evaporation to dryness, and a strong heat, the nitrat of iron is decomposed, while the earthy nitrats remain unaltered. They are of course dissolved by the water, but the red oxide of iron is left untouched.

Properties.

Vauquelin has lately discovered a method of obtaining the oxynitrat of iron in crystals. When concentrated nitric acid is kept for some months in contact with the black oxide of iron, solution slowly takes place, and crystals nearly colourless are formed, which have the figure of rectangular four-sided prisms, terminated by dihedral ridges. These crystals have an acrid and inky taste, and are very deliquescent. Their solution in water has a red colour, and the alkalies precipitate from it red oxide of iron *.

Crystals.

* Fourcroy, vi. 205.

Sp. 2. *Hyperoxymuriat of Iron.*

When a current of oxymuriatic acid is made to pass through water having red oxide of iron diffused through it, the oxide is dissolved, though with considerable difficulty. But Mr Chenevix, to whom we are indebted for this experiment, has not examined the properties of the hyperoxymuriat which must be formed during the process.

II. Incombustible.

Sp. 3. *Muriated Iron.*

Muriatic acid attacks iron with great rapidity; hydrogen gas is emitted in consequence of the decomposition of water, and the iron is oxidized and dissolved. This acid dissolves likewise the oxides of iron much more readily than any other, and for that reason it is usually employed to take out iron-marks from linen, and to remove particles of rust, which often adhere with great obstinacy to glass vessels. Muriatic acid combines both with the black and red oxides of iron, and forms with each of them a peculiar salt, the properties of which have been lately described by Mr Davy. Their existence had been previously pointed out by Proust. The common muriat of iron, usually obtained by dissolving iron or its oxides in muriatic acid, is a mixture of these two salts.

1. *Muriat of iron.* When iron-filings are dissolved in muriatic acid, the solution, provided it be excluded from the air, is of a pale green colour, and yields, when evaporated, crystals of muriat of iron of a pale green, which are extremely soluble in water, and soluble also, accord-

Book II. Division II. Properties.

ing to Davy, in alcohol. The solution attracts oxygen from the air and from nitric acid. It absorbs nitrous gas even in greater quantity than sulphat of iron, and acquires, when saturated, a dark brown colour, and a much more astringent taste than muriat of iron in its usual state. When heated, the greatest part of the gas is driven off, some red oxide of iron is precipitated, and some ammonia formed, precisely as happens to a solution of sulphat of iron impregnated with nitrous gas*. This salt may be formed very readily by dissolving sulphuret of iron in muriatic acid; the sulphureted hydrogen gas evolved preventing the absorption of oxygen from the atmosphere†.

2. *Oxymuriat of iron.* This salt may be formed by dissolving the red oxide of iron in muriatic acid, by treating the muriat of iron with nitric acid, or simply by exposing it in solution to the air. The solution of this salt is of a deep brown; its odour is peculiar, and its taste, even when much diluted with water, is exceeding-

Properties.

ly astringent. When evaporated to dryness, it yields an uncrystallizable orange-coloured mass, which deliquesces in the air, and is soluble in alcohol. This salt gives a yellow tinge to animal and vegetable substances, as is the case with oxymuriatic acid. When sulphuric acid is poured upon it, the odour of oxymuriatic acid is perceptible. This salt does not absorb nitrous gas. When sulphureted hydrogen gas is made to pass through it, part of the oxygen is abstracted, and the salt is converted into muriat of iron‡.

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* Davy, p. 180. † Davy, *Journal of the Royal Institution*, i. 398.
‡ Ibid. p. 181.

When this salt is distilled, oxymuriatic acid passes over, and the iron is reduced to the state of black oxide. This acid is also formed and exhaled during the solution of red oxide of iron in muriatic acid, at least if the solution be promoted by the application of heat.

If the heat be increased after the oxymuriat of iron is evaporated to dryness, the whole salt sublimes, not however in the state of oxymuriat, but of simple muriat, which is capable of crystallizing. The whole of these changes are easily explained. Oxymuriat of iron contains more acid than muriat. This excess flies off, and carries with it the second dose of oxygen of the oxide. The iron, thus reduced to the state of black oxide, sublimes in combination with the rest of the muriatic acid *.

Sp. 4. *Sulphated Iron.*

Concentrated sulphuric acid acts but very slowly upon iron, unless it be assisted by heat. In that case the metal is oxidized, and sulphurous acid gas exhaled. But diluted sulphuric acid dissolves iron with great rapidity, and abundance of hydrogen gas is emitted. In this case the water is decomposed; its oxygen combines with the iron, while its hydrogen is emitted. The solution has a green colour, and when evaporated immediately, yields crystals of *sulphat* of iron; but if allowed to remain exposed to the atmosphere, it gradually attracts more oxygen, and is converted into *oxysulphat*, unless it contains an excess of acid; which retards, and when sufficiently abundant, prevents the change.

* See on this subject the experiments of the Duc d'Ayen.

Book II. Division II. History.

1. *Sulphat of iron.* This salt was known to the ancients, and is mentioned by Pliny under the names of *misy*, *sory*, and *calchantum**. In commerce it is usually denominated *green vitriol* or *copperas*. It is not prepared by dissolving iron in sulphuric acid, but by moistening the pyrites which are found native in abundance, and exposing them to the open air. They are slowly covered with a crust of sulphat of iron, which is dissolved in water, and afterwards obtained in crystals by evaporation. Sometimes the salt is found ready formed, either in a state of solution in water or mixed with decayed pyrites. In some cases it is found necessary to roast the pyrites before they can be made to undergo spontaneous decomposition. This is most probably owing to the compact state of the pyrites in these cases, and the absence of all uncombined iron. Pyrites is in fact a supersulphuret of iron. The roasting reduces it to the state of sulphuret, which decomposes very readily.

Properties.

Sulphat of iron has a fine green colour. Its crystals are transparent rhomboidal prisms, the faces of which are rhombs with angles of 79° 50′ and 100° 10′, inclined to each other at angles of 98° 37′ and 81° 23′ †. It has a very strong styptic taste, and always reddens vegetable blues. Its specific gravity is 1.8399 ‡. It is soluble in about two parts of cold water, and in $\frac{1}{4}$ths of its weight of boiling water. It is insoluble in alcohol. When exposed to the air, its surface gradually becomes opaque, and is covered with a yellow powder; because

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* Lib. xxxiv. c. 12. † Hauy, *Jour. de Min.* An. v. 542.
‡ Hassenfratz, *Ann. de Chim.* xxviii. 12.

it absorbs oxygen, and is partially converted into oxysulphat. This change takes place much more rapidly and completely if the salt be moistened with water. The cause of these phenomena was first explained by Scheele.

When heated it melts, gradually loses its water of crystallization, and by a strong heat sulphurous acid is driven off, and there remains behind a red powder, formerly known by the name of *colcothar of vitriol*, which seems to be a mixture of brown oxide of iron and oxysulphat. When this salt is distilled, there comes over first water slightly acidulated with sulphuric acid, and afterwards a very strong fuming acid, formerly known by the name of glacial oil of vitriol, and which is now known to be a compound of sulphuric and sulphurous acids. The residuum is the same mixture of oxide and oxysulphat which is obtained by calcination in the open air. This decomposition, which sulphat of iron undergoes when heated, enables it in many cases, in a high temperature, to act nearly the same part as sulphuric acid. Hence it is often employed by manufacturers to disengage the weaker acids from their bases.

This salt, according to Bergman, is composed of

Composition.

39 acid
23 oxide
38 water

100 *

* *Opusc.* i. 37.

Book II. Division II.

According to Kirwan, of 26 acid
28 oxide
8 water of composition
38 water of crystallization

100 *

It cannot be doubted, I think, that the black oxide of iron is capable of combining intimately with water, and of forming a *hydrat*, as well as the oxide of copper.

Hydrat of iron.

The colour of this hydrat is *green*; hence the reason that the black oxide of iron, when precipitated from acids by means of alkalies, has a green colour. It is in the state of hydrat. When the water is driven off by heat, the oxide assumes its natural black colour. The oxide, which constitutes a part of the sulphat of iron, is also combined with water, and in the state of a hydrat. Mr Kirwan, therefore, has, with great propriety, distinguished between the water of crystallization and that part which is a necessary constituent of the salt.

When the crystals of sulphat of iron are moderately heated, they assume at first a white colour; the same change of colour is observed when the salt, in the state of powder, is infused in alcohol. Hence we see the separation of the water changes the colour from green to white; and if water be now poured on the white powder, it becomes again green.

The sulphat of iron is decomposed by the alkaline phosphats and borats, and by the greater number of those salts whose base forms an insoluble compound

* *On Mineral Waters*, Table iv.

with the sulphuric acid, as nitrat of silver, of lead, of barytes, &c.

2. *Oxysulphat.* This salt exists ready formed in what is called the *mother water of vitriol*, or the brown liquid which remains after all the sulphat of iron has been extracted by crystallization from those waters which contain it. The properties of this salt were first accurately described by Mr Proust. It may be formed by exposing the solution of sulphat of iron to the open air for some time, or by pouring into it nitric acid, and applying heat *.

This salt has a yellowish red colour. It does not afford crystals; and when evaporated to dryness, soon attracts moisture, and becomes again liquid. It is exceedingly soluble in water, and also in alcohol. By this last liquid it may be separated from the sulphat of iron, with which it is always mixed in the *vitriol* of commerce. When exposed to the air, it gradually deposites red oxide, or rather oxysulphat with excess of base.

A great number of substances have the property of depriving this salt of its excess of oxygen, and of converting it into sulphat of iron. This is the case with iron. When the solution of oxysulphat is mixed with iron filings, and kept for some time in a well-covered vessel, part of the iron is dissolved by abstracting the second dose of oxygen from the oxide, and the whole is converted into sulphat. The same change is produced by tin, and probably also by all the salts of tin which

* During this change a quantity of ammonia is also formed. Hence not only the nitric acid but some water also is decomposed. See Davy's *Researches*, p. 157.

Book II. Division II.

contain that metal combined with a minimum of oxygen. Sulphureted hydrogen produces that change instantaneously when made to pass through a solution of oxysulphat *. That gas has the property of reducing the oxides of iron to a minimum of oxygen; but it does not bring them to the metallic state. Hence the reason that it does not precipitate iron from its solution in acids.

On the other hand, all those bodies which part with oxygen very readily, convert the sulphat of iron into oxysulphat. Hence this change is produced by the nitric and oxymuriatic acids, by the oxymuriats, the muriat of gold, &c.

Absorbs nitrous gas.

The solution of sulphat of iron has the property of absorbing a great quantity of nitrous gas, and at the same time it acquires a yellowish colour. When this solution is heated without being exposed to the air, the greatest part of the nitrous gas is driven off unchanged; but a small portion of it is decomposed, a little red oxide of iron is precipitated, and some ammonia formed, owing to the decomposition of a little of the water of the solution, and the combination of its hydrogen with the azote of the nitrous gas. From the experiments of Mr Davy, it appears that 910 parts of a solution of sulphat of iron, of the specific gravity 1.4, absorb 5.72 parts of nitrous gas; 4.28 of these are emitted unaltered on the application of heat, and 1.44 are decomposed. This ingenious gentleman calculates that 1 part of water was also decomposed; that the oxygen furnished by these two bodies amounted to 1.65, and that it com-

* Proust, *Ann. de Chim.* xxiii. 23.

bined with 4.1 parts of black oxide, and occasioned the precipitation of 5.75 parts of brown oxide, which was doubtless in the state of oxysulphat, with excess of base. Hence the ammonia formed must have amounted to about 0.8 *. The oxysulphat of iron has not the property of absorbing nitrous gas †. Chap. III.

Sp. 5. *Sulphite of Iron.*

Sulphurous acid attacks iron with rapidity, much heat is produced, and the solution assumes at first a brown colour, which gradually passes into a green. During this solution no hydrogen gas is emitted except a few bubbles at first. The iron is oxidized at the expence of the acid, part of which is decomposed; its oxygen combines with the iron and converts it into black oxide, while its sulphur combines with the sulphite of iron as it forms. The salt, therefore, which is obtained by this process, is not pure sulphite of iron, but that salt combined with sulphur. These phenomena were first described by Berthollet ‡. When sulphuric acid or muriatic acid is poured into this solution the sulphurous acid is disengaged with effervescence; and if these acids be added in sufficient quantity a portion of sulphur is precipitated.

When the solution is exposed to the air, crystals of sulphite of iron are formed, and at the same time a red powder is deposited, probably consisting of *oxysulphite* of iron with excess of base, and combined with sulphur. The crystals dissolved in water and exposed to the air are gradually converted into sulphat of iron §. Varieties.

* Davy's *Researches*, p. 170.
† Ibid.
‡ *Ann. de Chim.* ii. 58.
§ Fourcroy, vi. 200.

Book II. Division II.

Thus there are two varieties of sulphited iron, *simple sulphite* and *sulphureted sulphite*. The first of these is insoluble in alcohol; but that liquid dissolves the second: the first, when exposed to the air, is converted into sulphat, but the second remains unaltered *.

Sp. 6. Phosphated Iron.

PHOSPHORIC ACID has but little action upon iron. However, if that metal remain exposed to the contact of phosphoric acid, or even to the solutions of salts which contain that acid, it is gradually oxidized, and converted into phosphat of iron. The properties of phosphated iron have not been examined with attention. Scheele has shewn that the acid combines with both oxides, and forms of course both a *phosphat* and *oxyphosphat* of iron. Fourcroy and Vauquelin have lately ascertained that there are two varieties of this last salt; one which had been already described by Bergman, Meyer, Klaproth, and Scheele, and another with excess of base, and consequently a *suboxyphosphat*, which these philosophers first observed.

Varieties.

1. *Phosphat of Iron.* When sulphat of iron dissolved in water is mixed with a solution of phosphat of potass, a blue powder precipitates, which is phosphat of iron. This powder is insoluble in water, and does not lose its colour when exposed to the air †. This salt is found native, and constitutes the colouring matter of a blue mineral called *native prussian blue*, found in bogs, and first analysed by Klaproth. *Native prussian blue*, as it

* Fourcroy, vi. 200.

† Scheele, Crell's *Annals*, i. 115. Engl. Trans.

is called, when dry out of the earth, is at first often colourless; but when exposed to the air, it becomes blue. The cause of this change has not been ascertained.

2. *Oxyphosphat of Iron.*—This salt may be readily procured by mixing together the solutions of oxymuriat of iron and phosphat of potass or soda. A white powder immediately falls, which is oxyphosphat of iron.

This salt, like almost all the phosphats, is soluble in acids, but precipitated undecomposed by ammonia. It is almost insoluble in water, as it requires more than 1500 parts of that liquid to dissolve one part of oxyphosphat. When heated violently, it melts into an ash-coloured globule *. When mixed with charcoal, and heated to redness, it is converted into phosphuret of iron.

3. *Suboxyphosphat of Iron.*—When the oxyphosphat of iron is treated with the pure fixed alkalies, a red, or rather brownish-red, powder is separated, while the alkali combines with phosphoric acid. This powder was examined by Fourcroy and Vauquelin, and found by them still to contain a portion of acid. It is therefore merely oxyphosphat with excess of base. This salt is scarcely soluble in acids or in water; but it dissolves readily in the white of an egg, or in the serum of blood, and communicates to these liquids a brown or red colour. Its solubility is increased, and its colour heightened, by the presence of a portion of fixed alkali †. This is the salt which gives a red colour to the blood.

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* Bergman, iii. 118.

† Fourcroy, ix. 152.

Book II. Division II.

Sp. 7. *Carbonated Iron.*

LIQUID carbonic acid, when kept in contact with iron, attacks it slowly, and dissolves a sufficient quantity of it to acquire a sensibly chalybeate taste. When exposed to the air, the iron is gradually precipitated in the state of oxide*; and by boiling it is deposited in the form of a yellow ochre, still retaining a portion of acid. This carbonat often exists native in mineral waters. It may be obtained also by precipitating sulphat of iron by means of an alkaline carbonat. In that case it is always in the form of a green mass.

Rust. RUST may be considered as an oxycarbonat of iron; for it consists of the red oxide of that metal combined with carbonic acid. Hence it dissolves in acids with effervescence, and when heated gives out carbonic acid gas: the residuum in that case is black oxide of iron†. Its brown colour seems to be owing to the presence of water. From the experiments of Bergman, carbonat of iron seems to be composed of about

24 acid
76 oxide

100‡

Stahl's tincture of Mars. The liquid known by the name of Stahl's tincture of Mars, because it was discovered by that illustrious chemist, has not been examined by modern chemists; but it appears to be a triple, or rather quadruple saline compound. It is formed by pouring a solution of oxynitrat of iron into liquid carbonat of potass: a red

* Bergman, i. 33. † Fourcroy, vi. 215. ‡ Bergman, ii. 394.

powder first precipitates, which is redissolved by agitating the mixture. The liquid of course is an *oxynitrocarbonat of potass and iron.* But the combination is not permanent; for the liquid soon deposites a red powder.

Sp. 8. *Fluat of Iron.*

Fluoric acid attacks iron with violence; hydrogen gas is emitted, and the metal oxidized and dissolved. The solution has an inky taste; and when evaporated does not crystallize, but assumes the form of a jelly. In this state it is undoubtedly an *oxyfluat* of iron. Heat decomposes it by expelling the acid. The same effect is produced by sulphuric acid. Fluoric acid also dissolves the red oxide of iron, and forms the same salt *.

Sp. 9. *Borat of Iron.*

Boracic acid acts very feebly upon iron; but borat of iron may be obtained very readily by pouring liquid borat of soda into a solution of sulphat of iron. A pale yellow powder immediately precipitates, which is the salt required. This salt is insoluble in water. Before the blow-pipe it melts readily into a globule of glass †.

III. Combustible Salts.

Sp. 10. *Acetated Iron.*

The acetic acid dissolves iron with rapidity, produ-

* Scheele, i. 34.

† Id. Crell's *Annals*, i. 114. Eng. Transl.

Book II. Division II.

cing an effervescence, and, like the other acids, it forms a salt with each of the oxides of that metal; but the properties of these salts have not been examined with attention.

1. *Acetat of Iron.*—This salt, as Mr Davy affirms, may be easily procured by dissolving sulphuret of iron in acetic acid *. It yields by evaporation crystals of a green colour, in the form of small prisms. It has a sweetish styptic taste, and its specific gravity is 1.368†. By exposure to the air, or by the application of heat, it is converted into *oxacetat*.

2. *Oxacetat of Iron*, is a reddish-brown solution, incapable of yielding crystals, and assumes the form of a jelly when evaporated. It is deliquescent. This salt is much employed by calicoe printers, because it is more easily decomposed than any other of the oxygenized salts of iron. They prepare it, either by mixing together sulphat of iron and acetat of lead, and leaving the solution exposed to the air, or by dissolving iron in an impure acetic acid, obtained by distilling wood.

The acetats of iron are decomposed by heat, and the iron left in the state of red or black oxide, according to the temperature.

Sp. 11. *Succinat of Iron.*

Succinic acid dissolves the oxide of iron, and yields by evaporation small brown transparent radiated crystals ‡. This salt is insoluble in water. Succinic acid accordingly separates iron from all other solutions.

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* *Journal of the Royal Institution*, i. 308.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Wenzel's *Verwand.* p. 240. Grindel's edit.

When succinat of soda is dropt into solutions containing iron, a brownish red precipitate falls in light fleaks, which is succinat of iron *.

Sp. 12. *Benzoat of Iron.*

This salt forms yellow crystals. It has a sweet taste. It is soluble in water and alcohol. It effloresces in the air. Heat disengages the acid †.

Sp. 13. *Oxalated Iron.*

Oxalic acid attacks iron rapidly, and dissolves it with effervescence, and forms a peculiar salt with each of its oxides.

1. *Oxalat* is obtained by dissolving iron or its black oxide in that acid, and evaporating the solution. Prismatic crystals of a green colour and sweet astringent taste are formed, very soluble in water with an excess of acid, which fall to powder when heated. They are composed of . . . . . 55 acid
45 oxide

100

2. *Oxygenized Oxalat* may be obtained by dissolving red oxide of iron in oxalic acid, or by exposing the first salt to the air in a digesting heat. It has the form of a yellow powder scarcely soluble in water, and incapable of crystallizing ‡.

Oxalic acid readily dissolves the oxides of iron even when combined with gallic acid. Hence it is often used

* Gehlen, Klaproth's *Beitrage*, iii. 63.
† Trommsdorf, *Ann. de Chim.* xi. 314.
‡ Bergman i. 268.

Book II. Division II.

to take spots of ink out of linen; and superoxalat of potass is usually sold in this country for that purpose, under the name of *essential salt of lemons*.

Sp. 14. *Mellat of Iron.*

MELLITIC ACID precipitates iron from nitric acid in the state of an Isabella yellow powder, which is redissolved by the addition of muriatic acid *.

Sp. 15. *Tartrated Iron.*

TARTARIC ACID dissolves iron with effervescence, and combines with each of its oxides.

1. *Tartrat of Iron* may be formed, according to Retzius, by pouring tartaric acid into sulphat of iron, and applying heat to the solution. Lamellar crystals are formed, sparingly soluble in water, which possess the properties of tartrat of iron.

2. *Oxytartrat* is usually formed when iron is dissolved in tartaric acid, and heat applied to the solution. It has a red colour, does not crystallize, but assumes the form of a jelly when evaporated.

Sp. 16. *Citrat of Iron.*

THIS salt has only been examined by Vauquelin. Citric acid dissolves iron slowly; the solution has a brown colour, and deposites small crystals of citrat of iron. When evaporated, it becomes black like ink, ductile while hot, but brittle while cold. This mass is evidently oxycitrat of iron. It is astringent, and very soluble in water.

* Klaproth's *Beitrage*, iii. 131.

Sp. 17. *Saccolat of Iron.*

SACLACTIC ACID does not precipitate iron from sulphuric acid *.

Sp. 18. *Malat of Iron.*

MALIC ACID forms with iron a brown solution, which does not yield crystals †.

Sp. 19. *Lactat of Iron.*

LACTIC ACID dissolves iron, and forms with it a brown liquid not capable of crystallizing ‡.

Sp. 20. *Suberat of Iron.*

SUBERIC ACID gives a deep yellow colour to sulphat of iron, but occasions no precipitate §.

Sp. 21. *Gallat of Iron.*

MR PROUST first observed, that the gallic acid does not occasion any precipitate when poured into salts of iron containing that metal in the state of black oxide. Hence it follows that the gallat of iron, if it be formed in these cases, is very soluble in water and without colour; but when gallic acid is poured into the oxiginized salts of iron, the solution becomes black, and a black precipitate, composed of gallic acid and red oxide of iron, immediately begins to fall; but it is so very fine and light, that the greater part of it remains long suspended; and if a quantity of mucilage or syrup be

* Scheele, ii. 80.
† Scheele, Crell's *Annals*, ii. 10. Eng. Trans.
‡ Scheele, ii. 65.
§ Bouillon Lagrange, *Ann. de Chim.* xxiii. 48.

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Writing ink.

mixed with the solution, the precipitate remains suspended altogether. It is this solution which constitutes writing *ink*. But ink is usually made by mixing the sulphat of iron of commerce with a saturated solution of nutgalls. Now the sulphat of commerce is a mixture of sulphat and oxysulphat of iron. That part of the iron which is in the state of sulphat forms at first a colourless solution; but by attracting oxygen from the atmosphere, it gradually becomes black. Hence the reason that ink is often pale at first, but becomes black when the writing dries, in consequence of the absorption of oxygen.

Gallat of iron is soluble in acids without decomposition, but it loses its colour in very strong acids. Hence the reason that these acids destroy the colour of writing.

Sp. 22. *Prussiated Iron.*

The combination formed between the prussic acid and iron has been the object of a great many researches, and has given occasion to several curious and important discoveries. We are indebted to Mr Proust for the fact that the prussic acid, like all other acids hitherto tried, is capable of forming a peculiar salt with each of the oxides of iron.

1. *Prussiat of Iron.*—This salt may be formed by pouring triple prussiat of potass into a solution of sulphat of iron. The salt precipitates in the form of a white powder. It is not altered by sulphuric and muriatic acids. When exposed to the air it absorbs oxygen with great rapidity, and passes to the state of oxyprussiat. Oxymuriatic and nitric acids produce the same change.

2. *Oxyprussiat of Iron.*—This salt is formed when

triple prussiat of potass is poured into oxysulphat of iron, or into the solution of any oxygenated salt of iron. A beautiful blue precipitate appears, which is the salt. It is not altered by the acids. Sulphureted hydrogen gas converts it into prussiat by absorbing oxygen. When it is mixed with iron-filings, and kept in water in a close vessel, it is also converted into prussiat, the iron absorbing the second dose of oxygen from the red oxide *.

IV. Metallic Salts.

Sp. 23. *Arseniated Iron.*

Arsenic acid dissolves iron when assisted by a digesting heat; and if the experiment be made in an open vessel, the solution at last assumes the form of a jelly; but in a close vessel this does not happen. When one part of iron filings and four parts of arsenic acid are distilled together to dryness, inflammation takes place, and at the same time both arsenic and white oxide of arsenic are sublimed †. Arsenic acid, as we see from these facts, is capable, like other acids, of combining with both the oxides of iron, and of forming *arseniat* of iron and *oxarseniat* of iron. Both of these salts have been found native in Cornwall, and have been lately described and analysed with great accuracy by Bournon and Chenevix.

1. *Arseniat of Iron.* This salt may be formed by pouring arseniat of ammonia into sulphite of iron. The salt precipitates in the state of a powder, insoluble in

* Proust, *Ann. de Chim.* xxii. 88. † Scheele, i. 177.

water. It exists native crystallized in cubes, which in some instances have their alternate angles truncated. Their colour is usually dark green, and their specific gravity 3 *. When heated, the iron attracts oxygen from the acid, and passes to the state of red oxide, while white oxide of arsenic sublimes. This native salt is usually contaminated with a little copper. The artificial arseniat, according to the analysis of Chenevix, is composed of . . . . . 38 acid

43 oxide

19 water

100

The native (abstracting the impurities) was found by the same accurate chemist to be composed of about

36 acid

52 oxide

12 water

100 †

2. *Oxarseniat of Iron.*—This salt may be formed by precipitating oxysulphat of iron with arseniat of ammonia, or by boiling the arseniat of iron in nitric acid. The native arseniat is sometimes found converted into this salt in consequence of the absorption of oxygen from the air. It has then a brownish-red colour. According to the analysis of Chenevix, the artificial oxarseniat is composed of

* Bournon, *Phil. Trans.* 1801, p. 190.

† Ibid. p. 229.

42.4 acid
37.2 oxide
20.4 water

100.0 *

Sp. 24. *Tungstat of Iron.*

This salt exists native, and is known to mineralogists by the name of *Wolfram*. It may be formed by precipitating sulphat of iron by means of the tungstats. It is an insoluble powder, possessing properties similar to native tungstat of iron. As this native salt contains also manganese, and is not therefore a pure tungstat of iron, it will be proper to defer the description of it to the Second Part of this Work.

Sp. 25. *Molybdat of Iron.*

The alkaline molybdats precipitate iron brown from its solution in acids †.

Sp. 26. *Columbat of Iron.*

This compound occurs native in North America, though only a single specimen is at present known, the specimen from which Mr Hatchett extracted Columbic acid. This specimen had a dark brownish-grey colour, a lamellated structure, a vitreous lustre, and a specific gravity of 5.918 : was moderately hard and very brittle. It was decomposed by repeated fusions with potass, which abstracted its acid; and digestions in mu-

* *Phil. Trans.* 1801, p. 225. † Scheele, i. 248.

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riatic acid, which dissolved its iron. Its component parts, according to Mr Hatchett's analysis, are

21.0 oxide of iron
77·5 columbic acid

98.5 *

V. Triple Salts.

Sp. 27. *Tartrat of Potass-and-iron.*

This triple salt was formerly called *tartarised tincture of Mars*, *chalybeated tartar*, and *tartarised iron*. It may be formed by boiling two parts of tartar and one of iron-filings, previously made up into a paste, in a proper quantity of water. The liquor by evaporation deposites crystals, which form the salt wanted.

Genus VII. Salts of Tin.

Though several of the salts of tin are of great importance in the art of dyeing, and have been known to manufacturers ever since the discovery of the scarlet dye, of which the oxide of tin constitutes a necessary ingredient, it is only of late that the nature and constitution of these salts have been examined with any kind of precision, and that a satisfactory explanation has been given of the curious properties which some of them possess, and the great changes to which they are liable. For the progress which this branch of the science has

* Hatchett, on a Mineral Substance from North America. *Phil. Trans.* 1802.

made, we are chiefly indebted to Adet, Pelletier, and Proust. Chap. III.

Tin, like iron, combines with two doses of oxygen, and forms two distinct oxides, with each of which several of the acids are capable of combining; and those salts which contain the metal oxydized to a minimum are extremely ready to absorb oxygen, and to pass into the state of oxygenized salts. The salts of tin may be distinguished by the following properties:

1. Most of them are more or less soluble in water, and the solution has usually a yellowish or brownish tinge. Characters.

2. Triple prussiat of potass occasions a white precipitate when dropt into these solutions.

3. Hydrosulphuret of potass occasions a black precipitate; sulphureted hydrogen gas, a brown precipitate.

4. Neither gallic acid nor the infusion of nutgalls occasions any precipitate.

5. When a plate of lead is put into some solutions of tin, that last metal is separated either in the state of metal, or of white oxide: but this does not happen in every solution of tin.

6. When muriat of gold is poured into solutions containing tin combined with a minimum of oxygen, a purple-coloured precipitate falls.

The salts of tin were formerly distinguished by the epithet *jovial*, because *Jupiter* was the name by which the alchymists distinguished that metal.

I. Detonating Salts.

Sp. 1. *Nitrated Tin.*

Nitric acid acts with amazing energy upon tin, and converts it into an oxide with the evolution of a great deal of heat; but there seems to be but a very

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feeble affinity between that acid and the oxides of tin. Hence the union which they form is but of transient duration, the oxides separating when any attempt is made to concentrate the solution. This has been long known to chemists, and has occasioned a variety of attempts to make the solution of tin in nitric acid more permanent; but these attempts, as might have been expected, have not been attended with success.

Action of nitric acid on tin.

When nitric acid of the specific gravity 1.114 is poured upon tin, the metal is dissolved rapidly with effervescence and a great elevation of temperature, which ought to be moderated by plunging the vessel containing the mixture in cold water. In this case the oxygen is chiefly furnished by the water, and the tin is only combined with a minimum of oxygen. The solution, therefore, which is of a yellow colour, is a real *nitrat* of tin. It becomes gradually opaque, and deposites a white powder, which is an oxide of tin with a minimum of oxygen, as Proust has demonstrated. This oxide separates in greater abundance if the solution be heated. During the solution of the tin a quantity of ammonia is formed, as Morveau first observed. When potass is dropt into the liquid, this ammonia becomes sensible by its odour. Hence we see that, during the solution, both water and nitric acid have been decomposed; their oxygen combined with the tin, and the hydrogen of the one uniting with the azote of the other, formed ammonia. If a little nitric acid be poured in and heat applied, the tin precipitates in the state of a peroxide*.

When nitric acid, of the specific gravity 1.25, is poured upon tin, a very violent action takes place, the

* Proust, *Jour. de Phys.* li. 173.

Chap. III.

No oxynitrat.

metal is oxidized to a maximum, and the whole of it separates from the liquid. Hence we see that there is no *oxynitrat* of tin; the peroxide of that metal, not being susceptible of entering into combination with nitric acid. When the liquid is evaporated, nitrat of ammonia is obtained. Morveau found, that 1 part of strong nitric acid and $1\frac{1}{2}$ part of tin, when treated in a retort, gave out no gas, notwithstanding the violence of their action. Upon examining the liquid, he found that the ammonia formed amounted to $\frac{1}{20}$ of the weight of the whole *. Hence we see that; during the oxidation, both the acid and the water are decomposed; and that they are decomposed in such proportions, that their hydrogen and azote combine, and form ammonia, while the whole of their oxygen unites with the tin.

II. Incombustible.

Sp. 2. *Muriated Tin.*

Muriatic acid dissolves tin in considerable quantity when its action is assisted by heat. The water of the acid is decomposed, its oxygen combines with the tin, while the hydrogen is emitted in the form of gas. This gas has usually a fetid smell, owing, according to Mr Proust, to a quantity of arsenic which it holds in solution, and which is partly deposited on the sides of the jars in which the gas is kept. During the solution of the tin, the arsenic which it usually contains is precipitated in the metallic state in the form of a black powder; so that the quantity of arsenic contained in tin may be ascertained by dissolving it in muriatic acid,

* *Encyc. Method. Chim.* i. 632.

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provided that portion which is carried off by the hydrogen gas be also taken into account*. Muriatic acid combines with both the oxides of tin, and forms with them permanent salts.

1. *Muriat of tin.* This is the salt obtained by dissolving tin in about four times its weight of muriatic acid. The solution has a brownish-yellow colour, and yields when evaporated small needle-shaped crystals, soluble in water, and somewhat deliquescent. Their specific gravity is 2.2932†.

This salt has a strong affinity for oxygen, and absorbs it with avidity from the air, from oxymuriatic acid, and from nitric acid, and is converted into oxymuriat of tin, as Pelletier first observed. It absorbs oxygen also from arsenic acid, and the white oxide of arsenic. When these bodies are treated with muriat of tin, they are precipitated, completely deprived of oxygen, in the state of a black powder. Molybdic acid and yellow oxide of tungsten, or their combinations, when dropt into a solution of muriat of tin, immediately assume a blue colour, being changed into oxides with a minimum of oxygen. The red oxide of mercury, the black oxide of manganese, the white oxide of antimony, the oxides of zinc and of silver, are likewise deprived of their oxygen by this salt, and reduced to the metallic state. The oxygenized salts of iron and copper are also reduced to salts with a minimum of oxygen, and the muriat of gold occasions a purple precipitate, consisting of gold reduced to the state of purple oxide. For these interesting results we are indebted to Pelletier and

Deoxidizes metals.

* Proust, *Jour. de Phys.* li. 175.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

Proust. They afford a sufficient key to explain all the singular changes produced upon the greater number of metallic salts by this muriat*.

2. *Oxy-muriat of tin.* This salt may be formed very conveniently by the process first proposed by Pelletier, which consists in causing oxymuriatic acid gas to pass into a solution of muriat of tin till it be saturated, and then to expel the excess of acid by heat. But it was known long before this process was thought of, and was usually distinguished by the name of *smoking liquor of Libavius;* because Libavius, a chemist of the 16th century, was the discoverer of it. When equal parts of amalgam of tin† and oxymuriat of mercury are triturated together, and then distilled in a a retort with a very moderate heat, there passes first a colourless liquid, consisting chiefly of water, and afterwards a white vapour rushes all of a sudden into the receiver. This vapour condenses into a transparent liquid, which exhales a heavy dense smoke when exposed to the air, but does not smoke when confined in close vessels. This is the fuming liquor of Libavius, or oxymuriat of tin.

Smoking liquor of Libavius.

The theory of the process is obvious: The tin abstracts oxygen from the mercury, and at the same time combines with the muriatic acid. Muriats of mercury and of tin are also formed, and line the neck of the retort mixed with a quantity of pure mercury; and there remains behind an amalgam of tin, covered with a crust of muriat of tin‡. It had been long known that this

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* Pelletier, *Ann. de Chim.* xii. 225.—Proust, *Jour. de Phys.* li. 173.

† Composed of two parts of tin and one of mercury.

‡ Rouelle.

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liquid contained muriatic acid and tin. Adet endeavoured to shew that the acid was in the state of hyper-oxymuriatic*. His experiments were afterwards confirmed by Pelletier†; but Proust demonstrated the falsehood of his theory‡.

The white smoke constantly exhaled by this salt, prepared according to the process of Libavius, has also been accounted for by Adet. This salt is nearly destitute of water, and in this state it is exceedingly volatile. The vapour as it rises combines with the vapour of the atmosphere, and the smoke appears at the moment of the combination. When the salt is confined in a glass jar, either in moistened air or standing over water, it condenses gradually on the sides of the jar in the form of small crystals, having imbibed the water necessary for its crystallization from the air. When thrown into water, this substance produces heat, and at the same time dissolves if the quantity of water be sufficient. Adet ascertained, that when 7 parts of water are mixed with 22 parts of fuming muriat, the mixture condenses into a solid mass. This mass melts like ice when exposed to heat, and condenses again when cooled and agitated.

Oxymuriat of tin is capable of dissolving an additional dose of tin without effervescence or the exhalation of gas, and by that means is converted into muriat of tin. The new portion of tin in this case deprives the tin of the oxymuriat of its second dose of oxygen. Adet, however, found, that this solution did not succeed except in

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* *Ann. de Chim.* i. 5. ‡ Ibid. xii. 225. † *Jour. de Phys.* lvi. 217.

the oxymuriat, rendered solid by mixture with water, and then liquefied by heat *.

Liquid oxymuriat of tin yields by evaporation small crystals; and when heated sublimes in the same manner as fuming muriat. This salt is employed by dyers in great quantities, as it forms the basis of the scarlet dye. They usually prepare it by dissolving tin in nitro-muriatic acid; the consequence of which is, that the nature of the solution varies according to the proportion of the acids and the manner of dissolving the tin. In some cases, it is merely a muriat; in others, an oxymuriat; and, generally, it consists of a mixture of the two. Hence the difficulty of which dyers complain of forming with this solution the same shade of colour in different circumstances. This would be in a great measure removed by preparing the salt according to the process recommended by Pelletier.

Sp. 3. *Sulphat of Tin.*

When a cylinder of tin is plunged into sulphuric acid, scarcely any action can be perceived for some time; but the metal is gradually converted into white flakes on the surface, which fall to the bottom, and remain in the state of a white powder: at the same time bubbles of sulphurous acid make their escape. The properties of the compounds which this acid forms with tin have not been examined with accuracy. Kunkel, Wallerius, and Monnet, the chemists who have paid the greatest attention to the action of sulphuric acid on tin, attempted the solution by means of heat. In that case the acid

* *Ann. de Chim.* i. 16.

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is decomposed, sulphurous acid exhaled, and even sulphur developed if the heat be long enough continued. The metal is oxidized to a maximum, and the *oxysulphat* obtained is not crystallizable; but when evaporated assumes the form of a jelly; and when water is poured into the solution, the salt precipitates in the state of a white powder.

But if the action of the acid is not assisted by heat, or if tin combined with a minimum of oxygen be dissolved in sulphuric acid in either of these cases a *sulphat* of tin is formed, which yields, when evaporated, crystals in the form of fine needles, as was observed long ago by Monnet.

Sp. 4. Sulphite of Tin.

The action of sulphurous acid upon tin has been examined lately by Fourcroy and Vauquelin, during their experiments on the combinations which that acid is capable of forming. When a plate of tin is plunged into liquid sulphurous acid, it assumes a yellow colour, and afterwards becomes black. A black powder is precipitated, which is sulphuret of tin. A portion of the acid is decomposed; the tin is partly oxidized, and combined with the remainder of the acid, and partly precipitated in the state of sulphuret combined with the sulphur of the decomposed acid. There remains in solution sulphite of tin combined with a portion of sulphur; for sulphur precipitates when sulphuric acid is added to the solution *.

* Fourcroy, vi. 30.

Sp. 5. *Phosphat of Tin.*

PHOSPHORIC ACID has scarcely any action on tin unless when it is exposed dry and mixed with that metal to the action of a strong heat. In that case, part of the acid is decomposed, its phosphorus combines with one portion of the tin and forms a phosphuret, while the oxide of tin unites with the undecomposed acid and forms a phosphat *. This salt precipitates also when the alkaline phosphats are mixed with a solution of muriat of tin; and it may be formed by digesting oxide of tin in phosphoric acid. It is insoluble in water. Tin does not precipitate copper from muriatic acid. Phosphat of tin melts into a glass when heated †.

Sp. 6. *Carbonat of Tin.*

As far as is known at present, the oxides of tin do not combine with carbonic acid. Bergman failed in his endeavours to form this combination; and when the oxides of tin are precipitated from their solution in acids by alkaline carbonats, he found that their weight receives scarcely a perceptible increase ‡. Nor have the attempts of Proust to combine these bodies with carbonic acid been attended with more success §.

Sp. 7. *Fluat of Tin.*

FLUORIC ACID does not attack tin; but it dissolves its oxide, and forms with it a gelatinous solution,

* Pelletier, *Ann. de Chim.* xiii. 16.

† Wenzel's *Verwandtschaft*, p. 175.

‡ *Opusc.* ii. 329.

§ *Jour. de Phys.* li. 167.

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which has a strong disagreeable taste *. This fluat may be formed also by mixing together an alkaline fluat and the muriat of tin.

Sp. 8. *Borat of Tin.*

Boracic acid does not attack tin; but borax produces a precipitate in the muriat of tin. The white powder which falls is insoluble in water: in a strong heat it melts into an opaque slag †.

III. Combustible Salts.

Sp. 9. *Acetat of Tin.*

Action of vinegar on tin vessels.

Acetic acid attacks tin very slowly, even when assisted by heat, and oxidizes and dissolves only a small portion of it. The spontaneous action of this acid on tin vessels, when in the state of vinegar, has been lately examined by Vauquelin. The subject was of importance, because vinegar is usually measured out in tin vessels. Now, as these vessels contain always a little lead, and as the salts of lead are all poisonous, it was of consequence to determine whether the vinegar acted on the vessel, and if it did, whether its action was confined to the tin or extended also to the lead; because in this last case the vinegar would be converted into a poison. The result of this investigation was, that a small portion of tin was dissolved, and that when the lead exceeded the sixth part of the tin, a small portion of it was also dissolved at that part of the vessel only which was in contact both with the vinegar and the air ‡.

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* Scheele, i. 34. † Wenzel's *Verwandtschaft*, p. 252

‡ *Ann. de Chim.* xxxii. 243.

When acetic acid is boiled upon tin, the metal is gradually dissolved, combining with oxygen at the expence of the water. The solution has a whitish colour, and yields by evaporation small crystals. This fact, first mentioned by Lemery, had been denied by Monnet, Westendorf, and Wenzel, who could only obtain from it a gummy mass. But Morveau established the truth of Lemery's observation, by crystallizing acetat of tin by spontaneous evaporation*. It is easy to account for the different results obtained by these chemists. The crystals were no doubt *acetat* of tin, the gummy mass *oxacetat* of tin.

Sp. 10. *Succinat of Tin.*

Succinic acid dissolves the oxide of tin when assisted by heat. The solution by evaporation yields thin, broad, transparent crystals†. Neither lead, iron, nor zinc, occasion any change in the solution of this salt‡.

Sp. 11. *Benzoat of Tin.*

Neither tin nor its oxide is soluble in benzoic acid; but when benzoat of potass is poured into a solution of tin in nitro-muriatic acid, benzoat of tin precipitates. It is soluble in water by the assistance of heat, but insoluble in alcohol, and decomposed by the action of heat§.

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* *Encycl. Method. Chim.* i. 23.
† Wenzel's *Verwandt*, p. 241.
‡ Wenzel's *Verwantschaft*, p. 252.
§ Trommsdorf, *Ann. de Chim.* xi. 315.

Sp. 12. *Oxalat of Tin.*

OXALIC ACID attacks tin when assisted by heat. The metal is first blackened, and is then covered with a white crust of oxide. The solution, which has an austere taste, by slow evaporation yields prismatic crystals; but when evaporated rapidly by means of a strong heat, it leaves a mass resembling horn *.

Sp. 13. *Tartrat of Tin.*

THE tartrat of tin has never been examined by chemists. The acid does not attack the metal, but it dissolves the oxide of tin.

IV. METALLIC SALTS.

Sp. 14. *Arseniat of Tin.*

WHEN tin is treated with arsenic acid in a digesting heat, it is slowly oxidized at the expence of the acid, and the solution at last assumes the form of a gelatinous mass. Arsenic acid precipitates tin from acetic acid, and the alkaline arseniats occasion a precipitate when poured into muriat of tin. The precipitate is arseniat of tin in the form of an insoluble powder, which hitherto has not been examined †.

V. TRIPLE SALTS.

Sp. 15. *Tartrat of potass-and-tin.*

THIS triple salt may be formed by boiling together tartar and the oxide of tin in water. It is very soluble,

* Bergman, i. 269. † Scheele, i. 189.

and therefore its solution crystallizes with difficulty. No precipitate is produced in it by the alkalies or their carbonats *. Chap. III.

Sp. 16. *Nitrat of Ammonia-and-tin.*

The peroxide of tin is insoluble in nitric acid, but it dissolves when treated with nitric acid and ammonia. Hence the reason why a salt containing tin is often procured by the action of nitric acid on tin. Nitrat of ammonia is formed during the process †.

Genus VIII. Salts of Lead.

Though lead be one of the most abundant and useful metals, though it has been known from the earliest ages, and though it is without difficulty dissolved by the greater number of acids, its salts have not hitherto been much examined by chemists. This is to be regretted; because the various degrees of oxidizement of which it is susceptible, afford an excellent opportunity of ascertaining how many different salts it is capable of forming with each peculiar acid; and this once known, would probably lead to some general conclusions concerning the different classes of metallic salts. The salts of lead were formerly distinguished by the name of *saturn*, the title by which lead was known among the alchymists. They may be distinguished by the following properties:

1. A considerable number of them are scarcely soluble in water without an excess of acid. These before the blow-pipe yield very readily a button of lead. Characters.

* Thenard, *Ann. de Chim.* xxxviii. 35. † Ibid. xlii. 218.

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2. The solution of the soluble salts of lead in water is generally colourless and transparent.

3. They have almost all less or more of a sweet taste, accompanied with a certain degree of astringency.

4. Triple prussiat of potass occasions a white precipitate when poured into solutions containing salts of lead.

5. Hydrosulphuret of potass occasions a black precipitate. The same precipitate is produced by sulphureted hydrogen.

6. Gallic acid and the infusion of nutgalls occasion a white precipitate.

7. A plate of zinc kept in a solution of lead occasions either a white precipitate, or the lead appears in its metallic state.

Though lead is susceptible of combining with several doses of oxygen, it does not appear that each of its oxides is capable of combining with acids. As far as is known at present, it is only the first two oxides which possess this property, if we except the hyperoxymuriat, which contains the peroxide of lead. None of the attempts to combine the red oxide of lead with acids have been attended with success. The yellow oxide combines with all acids hitherto tried; the salts formed by means of that oxide alone have been hitherto examined: the combinations of the first oxide have been completely overlookcd, except by Mr Proust.

I. Detonating Salts.

Sp. 1. *Nitrated Lead.*

Nitric acid acts upon lead with considerable energy, provided it be not too much concentrated; first

Action of nitric acid on lead and its oxides.

converting it into a white powder, which is a suboxynitrat, and then dissolving it, especially when assisted by heat. The yellow oxide of lead is dissolved by nitric acid completely, and without effervescence; but the red oxide is rendered white; $\frac{6}{7}$ths of its weight are dissolved, and $\frac{1}{7}$th is converted into brown oxide, and remains undissolved *. Hence we see that it is the white oxide of lead only which combines with nitric acid. Six-sevenths of the red oxide are decomposed; the excess of oxygen combines with the remaining seventh, and converts it into brown oxide, while the base or yellow oxide combines with the acid. Thus we see that nitric acid does not combine with the red or brown oxide of lead, but it combines with the protoxide and yellow oxide, and forms with them two salts, which we shall distinguish, as usual, by the names of *nitrat* and *oxynitrat* of lead. The last has been long known; but the first has been pointed out within these few years by Mr Proust.

1. *Oxynitrat of Lead.*—This salt is always formed when lead is dissolved in nitric acid, unless there be present an excess of lead, and a strong heat be applied. It is formed also by dissolving the deutoxide or white lead in nitric acid. The solution is transparent and colourless, and when sufficiently concentrated by evaporation, crystallizes on cooling. The crystals are usually tetrahedrons, having their apex truncated, and sometimes six-sided pyramids, according to Rouelle. They are opaque and white, and have a silvery lustre. Their taste is sweetish and harsh. They are not altered by

* Proust.

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exposure to the air. They are soluble in $7\frac{1}{2}$ parts of boiling water *. Their specific gravity is 4.068 †. When heated they decrepitate, and then undergo a kind of detonation, emitting very brilliant sparks ‡. When they are triturated with sulphur in a hot mortar, a feeble detonation is produced, and the lead is reduced to the metallic state §.

Composition.

My experiments give the constituents of this salt as follows:

65.5	oxide
34.5	acid and water
100.0 ‖	

The oxide of lead is thrown down by alkalies in the state of yellow powder. Sulphuric, sulphurous, and muriatic acids combine with the oxide, and precipitate it in the state of a white powder. Iron occasions no precipitate though kept in the solution of oxynitrat of lead ¶.

2. *Nitrat of Lead.* This salt may be formed by boiling together a quantity of metallic lead and oxynitrat; a portion of the lead is dissolved at the expence of the deutoxide in the oxynitrat; and the whole is converted into the protoxide which, according to a very general law in chemistry, requires less acid to saturate it than the deutoxide. It may be formed also by boiling

* Gren's *Handbuch*, iii. 266.

† Hassenfratz, *Ann. de Chim.* xxviii. 12.

‡ Bergman, ii. 470. § Van Mons, *Ann. de Chim.* xxvii. 81.

‖ These proportions are founded on the component parts of sulphat of lead given below from Kirwan.

¶ Wenzel's *Verwandschaft*, p. 90.

nitric acid on a greater quantity of lead than it is capable of dissolving. In that case the salt usually crystallizes in cooling, and the solution is yellow*. This salt crystallizes in brilliant scales of a yellow colour, and very soluble in water†. It may be obtained also in regular octahedrons, composed of two four-sided pyramids applied base to base‡. The proportions of its component parts are still unknown.

Sp. 2. *Hyperoxymuriat of Lead.*

When the red oxide of lead is put into a Woulfe's bottle with water, and oxymuriatic acid gas is made to pass through it, the gas is absorbed, while the oxide acquires a brown colour, and is gradually dissolved. For this curious experiment we are indebted to Mr Proust. In this case the lead absorbs oxygen from the acid; and when the whole is oxidized to a maximum, a portion is dissolved, and hyperoxygenized muriat of lead formed. This salt is much more soluble than muriat of lead. It is very readily decomposed§.

II. Incombustible.

Sp. 3. *Muriat of Lead.*

Muriatic acid attacks lead when assisted by heat, and oxidizes and dissolves a portion of it; but its ac-

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* This experiment was made by Wenzel long ago; but it was impossible to draw the proper inference till the nature of the oxide was better understood. See his *Verwand.* p. 90.

† Proust, *Jour de Phys.* lvi. 206.

‡ These fine crystals were formed last winter by Mr Collins; a young gentleman who was at that time a pupil of mine.

§ Chenevix on Hyperoxygenized Muriatic Acid, *Phil. Trans.* 1802.

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tion is feeble and limited. It combines readily with the yellow oxide of lead. When poured upon the red oxide, it is converted partly into oxymuriatic acid by the assistance of heat, while the lead, reduced to the state of white oxide, combines with the remainder of the acid*. Thus we see that muriatic acid combines usually with yellow oxide of lead, and that it is incapable of combining with the red oxide of that metal; but in all probability it combines with the protoxide, though the experiment has not been tried. The compound of muriatic acid and lead at present known is in fact an oxymuriat. There are two varieties: the first neutral, long known; the second a submuriat.

1. *Muriat of Lead.* This salt may be formed readily by pouring muriatic acid or an alkaline muriat into a solution of nitrat of lead. The muriat precipitates in the state of a white powder. It has a sweetish taste. Its specific gravity is 1.8226†. It is soluble in 22 parts of cold water, and this solubility is increased considerably by the presence of an acid‡. It is soluble in acetic acid; a property by which it may be readily distinguished from sulphat of lead. When its solution in boiling water is allowed to cool, the salt crystallizes in very small six-sided prisms of a white colour, and brilliant appearance like sattin. These crystals are not altered by exposure to the air. When heated they melt readily, and when cold assume the appearance of a semitransparent, greyish-white mass, formerly distinguished by the name of *plumbum corneum*. When exposed to a strong heat, they partly

* Fabroni. † Hassenfratz, *Ann. de Chim.* xxviii. 12.
‡ Chenevix, Nicholson's *Jour.* iv. 223.

evaporate in a visible white smoke, and there remains behind a submuriat of lead; a substance which seems to have been first examined by Bergman*. The constituents of this salt are, according to

Composition.

Klaproth,	Kirwan, Crystals	Dried
13.5	18.23 . . .	17
86.5	81.77 . . .	83
100.0†	100.00	100‡

According to Kirwan's estimate, we may consider 100 parts of the crystallized salt as containing 76 parts of lead in the metallic state. This salt dissolves in nitric acid.

2. *Submuriat of Lead.* This salt may be procured either by treating muriat of lead with a pure alkali, or by decomposing common salt by means of four times its weight of litharge. In either case a white powder remains, which is the submuriat of lead. Vauquelin first pointed it out to the peculiar attention of chemists§. It had been previously mentioned by Bergman. It is insoluble in water. When heated, it assumes a fine yellow colour. Nitric acid dissolves the excess of oxide, and leaves muriat of lead in crystals. The fixed alkalies dissolve it without decomposition. This salt is employed as a yellow paint.

Properties.

Sp. 4. *Sulphat of Lead.*

SULPHURIC ACID does not attack lead while cold; but at a boiling heat it communicates a portion of its

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* Bergman, ii. 470. and iii. 325.

† *Beitrage*, ii. 275.

‡ On *Mineral Waters*, Table IV.

§ *Ann. de Chim.* xxxi. 3.

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oxygen, sulphurous acid gas is emitted, and the whole is converted into a thick white mass, which is sulphat of lead. It may be obtained readily by pouring sulphuric acid into acetat of lead, or by mixing this last salt with any of the alkaline sulphats. The sulphat of lead precipitates in the state of a white powder. This salt has but little taste. Its specific gravity is 1.8742 *. It is insoluble in alcohol and in nitric acid. According to Kirwan, it requires 1200 parts of water to dissolve it †. But when it contains an excess of acid, it is more soluble, and yields by evaporation small white crystals, which, according to Sage, have the form of tetrahedral prisms. It is found native crystallized, according to Kirwan, in four-sided oblique angled prisms ‡; according to Hauy, in regular octahedrons §. The native sulphat of lead, found in Paris mountain, Anglesey, is crystallized in four-sided pyramids; the specimens found at Leadhills in Scotland, are in transparent tables.

Composition.

According to the experiments of Kirwan, it is composed of . . . . . 23.37 acid
75.00 oxide
1.63 water

100.00

And 100 parts of it contain exactly 71 parts of lead in the metallic state ||.

* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† *Mineralogy*, ii. 211.

‡ Kirwan's *Min.* ii. 211.

§ *Jour. de Min.* An. v. p. 508.

|| Kirwan *on Mineral Waters*, Table iv.

The native sulphat of Leadhills, which is perfectly pure, is composed, according to Klaproth's analysis, of

70.50 oxide
25.75 acid
2.25 water

98.50*

Hence sulphat of lead, strongly heated, is composed of

73.5 oxide
26.5 acid

100.0

In close vessels this salt endures a considerable heat without alteration. I find that, after being dried in the temperature of about 400°, it may be heated to redness in a platinum crucible without losing any weight. On charcoal it melts, and the lead is quickly reduced.

When this salt is treated with alkalies, it is deprived of the greater part of its acid; but a portion still adheres. The white powder obtained by this process is therefore a subsulphat of lead.

Sp. 5. *Sulphite of Lead.*

SULPHUROUS ACID has no action whatever on lead. It absorbs oxygen from the red oxide of that metal, and is converted into sulphuric acid. But it combines with the deutoxide of lead, and forms with it a sulphite, which is in the state of a white powder, insoluble in water, and tasteless. Before the blowpipe on charcoal it melts, becomes yellow, and the lead is at last redu-

* *Beitrage*, iii. 166.

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ced*. Sulphite of lead, dried in a temperature of about 300°, is composed, according to my analysis, of

74.5 oxide
25.5 acid

100.0

When exposed to a red heat, it loses 5 *per cent.* of its weight; sulphurous acid exhales; and there remains a blackish mass composed of sulphat of lead and sulphuret. When treated with nitric acid, the sulphuret is decomposed, and crystals of nitrat obtained.

Sp. 6. Phosphat of Lead.

Phosphoric acid has but little action on lead; however, when allowed to remain long in contact with it, the metal is partly oxidized and converted into an insoluble phosphat. The phosphat of lead may be easily formed by mixing the alkaline phosphats with nitrat of lead. The salt immediately precipitates in the state of an insoluble powder †.

The salt is found native in different parts of the world. Its colour is then usually green or yellow, and it is often crystallized in six-sided prisms. It is insoluble in water unless there be a considerable excess of acid; but it is soluble in pure soda, and probably forms with it a triple salt ‡. When heated it melts, and assumes on cooling a regular polyhedral form. In a red heat it is decomposed by charcoal, which absorbs the oxygen from both of its component parts. The sul-

* Fourcroy and Vauquelin, *Connaissances Chimiques*, vi. 86.

† Margraf's *Verhaltniss des phosphori gegen die Metall.* i. 42. Wenzel's *Verwandtschaft*, p. 174.

‡ Vauquelin, *Jour. de Min.* No. 9. p. 6.

phuric and muriatic acids, decompose it by abstracting its base while cold; but these decompositions do not take place in a strong heat. Nitric acid dissolves it.

The yellow phosphat of lead, from Leadhills in Scotland, is composed, according to my analysis (abstracting the impurities with which it is usually mixed) of

18 acid
82 yellow oxide

100

With this analysis the constituents of the different varieties, as found by Klaproth, coincide almost exactly *.

Sp. 7. *Carbonat of Lead.*

Carbonic acid has no action whatever on lead, neither is it capable of dissolving its oxide. But it combines readily with the deutoxide, and forms a carbonat. This salt is most easily obtained by precipitating lead from its solution in nitric acid by the alkaline carbonats. By that process it is obtained in the state of a white powder. It is tasteless, and insoluble in water; but soluble in pure potass, in the same manner as the oxides of lead.

The *white lead* of commerce, employed as a paint, is merely a carbonat of lead, as Bergman first observed †. It is prepared by exposing thin plates of lead to the hot vapours of acetic acid. The metal is gradually cor-

White lead.

* Beitrage, iii. 146.

† *Opusc.* i 39. Proust has lately shewn the same thing, *Jour. de Phys.* lvi. 207.

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roded and converted into a carbonat, probably at the expence of the acid.

This salt occurs native in abundance. In that state it is usually white, and has a good deal of lustre. Its specific gravity is 7.2357 *. It is sometimes crystallized in six-sided prisms, terminated by six-sided pyramids, sometimes in regular octahedrons †, and sometimes in tables ‡. It is insoluble in water. When exposed to the action of the blow-pipe upon charcoal, the lead is immediately reduced to the metallic state.

This salt has been analysed by some of the most expert chemists. The constituents, as determined by their experiments, may be seen in the following Table:

Composition.

Bergman.	Chenevix.	Klaproth.	Proust.	
16	15	16.33	16.15	acid
84	85	83.67	83.85	deutoxide
100 §	100 ‖	100.0 ¶	100.0 **	

The mean of all these analyses is

15.87 acid
84.13 oxide

100.00

This differs very little from the estimate of Bergman, which may therefore be taken as the true standard.

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* Bournon, Nicholson's *Journal*, iv. 220.

† Hauy, *Jour. de Min.* An. v. 502.

‡ As at Leadhills in Scotland.

§ Bergman, ii. 393.

‖ Nicholson's *Journal*, iv. 221.

¶ Beitrage, iii. 165.

** *Jour. de Phys.* lvi. 207.

Sp. 8. *Fluat of Lead.*

Fluoric acid has no action on lead, though it dissolves a small proportion of the white oxide of that metal when there is an excess of acid; but the fluat of lead, formed by saturating the acid, is an insoluble powder, which melts easily before the blow-pipe, and lets go its acid. The acid is driven off also by sulphuric acid *.

Sp. 9. *Borat of Lead.*

Boracic acid has no action on lead; but borat of lead is precipitated in the state of white powder when borat of soda is mixed with nitrat of lead. Before the blow-pipe it melts into a colourless glass †. When one part of boracic acid is melted with two parts of red oxide of lead, the product, according to Reuss, is a greenish-yellow, transparent, hard, insoluble glass ‡.

III. Combustible Salts.

Sp. 10. *Acetat of Lead.*

Acetic acid, as Vauquelin has shewn, does not attack lead in close vessels; but it occasions its oxidizement when the lead is in contact both with the acid and the air, and the oxide is dissolved as it forms. The acetat of lead which is produced by this solution has been long known. It is mentioned by Isaac Hollandus and Raymond Lully. It received formerly a great variety of names; such as, *sugar of lead*, *sugar of Saturn*, History.

* Scheele, i. 33.

† Wenzel's *Verwandt*, p. 252.

‡ Reuss *de Sale Sedativo*.

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salt of Saturn, vinegar of Saturn, extract of Saturn, &c. The solution of lead in acetic acid was strenuously recommended by Goulard, a surgeon of Montpelier, as an excellent application in cases of inflammation. Hence it is often called *Goulard's extract.*

This salt is employed in considerable quantities by dyers and calico printers. They mix it with alum or with sulphat of iron, and by that means compose acetat of alumina or of iron, according to the process; salts which answer much better as mordants for fixing their colours than alum or green vitriol. It is prepared in considerable quantities both in this country and in Holland and France. The manufacturers distil their own acid in England and Holland from sour beer, and in France from sour wine. The different processes followed by manufacturers have been described by Weber * and Demachy †, and more lately by Pontier ‡.

Preparation.

These processes may be reduced to two; either lead in the metallic state is exposed to the action of the acetic acid, or the carbonat of lead is dissolved in it. In the first case, thin plates of lead are put into earthen vessels along with acetic acid. The portion of the lead near the surface, as soon as it is covered with a coat of oxide, is removed to the bottom of the vessel, and new plates are brought to the surface. These are incrusted in their turn, and removed to the bottom, where the oxide is dissolved. This change of place is continued daily till the acid has dissolved a sufficient quantity of

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* *Phys. Chem. Magazin.* i. 84. † *Laborant in grossen*, ii. 194.

‡ *Ann. de Chim.* xxxvii. 268.

lead. It is then filtered, and sufficiently concentrated by evaporation. As it cools, the acetat of lead precipitates in small crystals. Chap. III.

Other manufacturers dissolve the carbonat of lead, prepared by exposing the metal to the fumes of vinegar; or they make use of litharge in its stead, and the solution is evaporated in the usual way till the salt crystallizes. This process is considered as more expensive than the other: But might not native carbonat of lead, which is found abundantly in many places, be employed with advantage instead of these artificial oxides?

Properties. Acetat of lead is usually in the form of small needle-shaped crystals, which have a glossy appearance like satin, and are flat four-sided prisms, terminated by dihedral summits. Its taste is sweet and somewhat astringent. Its specific gravity is 2.345 *. It is but sparingly soluble in water, unless there be an excess of acid. When exposed to the air, it undergoes no change. Its constituents are easily separated. When it is dissolved in water, a small quantity of white powder usually falls. It is carbonat of lead, formed by the carbonic acid, which usually exists in water. When we blow through a solution of acetat of lead, the same white powder precipitates †.

This salt is decomposed by all those acids and their compounds which form with lead a salt nearly insoluble in water; as the sulphuric, phosphoric, muriatic, fluoric, oxalic, malic, &c. When heated, it is decomposed; and if it be distilled in a retort, very singular Products when distilled.

* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Proust, *Jour. de Phys.* lvi. 267.

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products are obtained. These products were first examined by Beccher; afterwards by Baumé, and more particularly by Pluvinet: But it is to Proust that we are indebted for the most precise information on the subject. By distilling 160 parts of sugar of lead, he obtained by a gentle heat 12 parts of water slightly acidulated with vinegar. Then by increasing the fire, there came over 72 parts of a yellow liquid, having the odour of alcohol, strong and agreeable, though mixed with an empyreumatic smell. When lime is added to the liquid, ammonia is disengaged, which existed in the liquid combined with a slight excess of acetic acid. When the liquid was saturated with potass, and allowed to remain for 24 hours, about $\frac{1}{3}$d of a part of oil separated and floated on its surface. This oil being separated by a syphon, was found to have a strong odour. The liquid was then distilled by means of a low heat. The first eight parts which came over were of the specific gravity 0.88. This liquid mixed with water exactly like alcohol. Its taste was strong; and its volatility scarcely inferior to that of ether. It burns rapidly, and with a large white flame when brought near a lighted candle. It contained manifestly a considerable portion of water*.

Sp. 11. *Succinat of Lead.*

Succinic acid scarcely attacks lead, but it dissolves its yellow oxide; and the solution, according to Wenzel, yields long slender foliated crystals†, scarcely soluble in water, but soluble in nitric acid. Succinic a-

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* Proust, *Jour. de Phys.* lvi. 209. † Wenzel's *Verwand*, p. 241.

cid does not precipitate lead from nitric or muriatic acid; but it occasions a precipitate in acetat of lead *.

Sp. 12. *Benzoat of Lead.*

Benzoic acid dissolves lead with difficulty. The solution yields by evaporation crystals of benzoat of lead of a brilliant white colour, soluble in alcohol and water; not altered by exposure to the air, but decomposed by heat, which drives off their acid. The sulphuric and muriatic acids separate the lead †.

Sp. 13. *Oxalat of Lead.*

Oxalic acid blackens lead, but it is scarcely capable of dissolving it; but it dissolves its deutoxide, and when nearly saturated deposites small crystalline grains of oxalat of lead. The same crystals are precipitated when oxalic acid is dropt into the nitrat, muriat, or acetat of lead dissolved in water. They are insoluble in alcohol, and scarcely soluble in water, unless they contain an excess of acid. They are composed, according to Bergman's analysis, of about

41.2 acid
58.8 oxide

100.0 ‡

Sp. 14. *Mellat of Lead.*

Mellitic acid occasions a white precipitate when

* Stockar de Neuforn *de Succino*, § 33.; as quoted by Gren, *Handbuch*, iii. 281.

† Trommsdorf, *Ann. de Chim.* xi. 316. ‡ Bergman, i. 267.

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dropt into nitrat of lead; but the precipitate is redissolved by the addition of nitric acid*.

Sp. 15. *Tartrat of Lead.*

TARTARIC ACID has no action on lead; but it combines with its oxide, and precipitates tartrat of lead in the state of an insoluble white powder, from the nitrat, muriat, and acetat of that metal. According to the analysis of Thenard, it is composed of

34 acid
66 white oxide

100†

Sp. 16. *Citrat of Lead.*

CITRIC ACID does not attack lead; but when dropt into acetat of lead, a citrat precipitates in the state of a difficultly soluble powder‡.

Sp. 17. *Saccolat of Lead.*

SACLACTIC ACID occasions a white precipitate when dropt into nitrat of lead §.

Sp. 18. *Malat of Lead.*

MALIC ACID does not attack lead; but when poured into a solution of lead in nitric or acetic acid, malat of lead is immediately precipitated ‖; and likewise, as Vauquelin has observed, when acetat of lead is poured into a solution containing malat of lime. This precipi-

* Klaproth's *Beitrage*, iii. 132.
† *Ann. de Chim.* xxxviii. 37.
‡ Wenzel's *Verwandtschaft*, p 184.
§ Scheele, ii. 80.
‖ Scheele, Crell's *Annals*, ii. 7. Eng. Transl.

tate is easily distinguished by the form of fine light flakes which it has, and by the facility with which it is dissolved by the acetic and weak nitric acids*.

Sp. 19. *Lactat of Lead.*

Lactic acid, when digested upon lead for several days, dissolves it. The solution has a sweet and astringent taste, and does not crystallize†.

Sp. 20. *Suberat of Lead.*

Suberic acid precipitates lead from the acetic and nitric acids‡.

IV. Metallic Salts.

Sp. 21. *Arseniat of Lead.*

Arsenic acid attacks lead in a digesting heat, communicates a portion of its oxygen, and converts it into arseniat of lead in the state of an insoluble white powder. When arsenic acid is poured into the solution of lead in nitric, muriatic, or arsenic acids, arseniat of lead precipitates in powder. When this salt is heated it melts; and if charcoal be thrown into the mass while in fusion, arsenic is volatilized, and the lead is reduced; the charcoal abstracting the oxygen from both of the component parts of the salt.

Arseniat of lead is completely insoluble in water. It has been found native. According to the analysis of Chenevix, it is composed of

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* *Ann. de Chim.* xxxv. 155. † Scheele, ii. 166.

‡ Bouillon Lagrange, *Ann. de Chim.* xxiii. 48.

33 acid
63 white oxide
4 water

100*

Sp. 22. *Molybdat of Lead.*

THE action of molybdic acid on lead has not been tried; but Scheele ascertained, that when dropt into the solution of lead in nitric or muriatic acid, molybdat of lead was immediately precipitated †. The precipitate from nitric acid is redissolved by adding nitric acid ‡.

This salt occurs native in Carinthia. Its composition was first detected by Klaproth. It has a yellow colour, and is completely insoluble in water. Its specific gravity is 5.706 §. Its crystals are cubic or rhomboidal plates. When heated, it decrepitates and melts into a yellowish mass. It is soluble in fixed alkalies and in nitric acid. Muriatic acid decomposes it by the assistance of heat, and carries off the lead. According to the analysis of Klaproth, it is composed of about.

34.7 acid
65.3 oxide

100.0 ||

Sp. 23. *Tungstat of Lead.*

NITRATED TUNGSTAT of potass occasions a white precipitate in nitrat of lead ¶.

* *Phil. Trans.* 1801, p. 199.
† Scheele, i. 246.
‡ Hatchett, *Phil. Trans.* 1796.
§ Ibid.
|| *Beitrage*, ii. 275
¶ Scheele, ii. 90.

Sp. 24. *Chromat of Lead.*

This salt may be formed by mixing together the solutions of nitrat of lead and an alkaline chromat. The chromat of lead, in that case, precipitates in the state of a red powder; but it exists native, and is indeed the compound from which chromic acid is usually obtained.

Its colour is red with a shade of yellow; and its crystals are four-sided prisms, sometimes terminated by four-sided pyramids. Its specific gravity is about 6. It is insoluble in water, but soluble in the fixed alkalies without decomposition. Nitric acid also dissolves it; but muriatic and sulphuric acids decompose it, precipitating the lead in the state of muriat or sulphat. According to the analysis of Vauquelin, it is composed of about . . . . . 34.9 acid
65.1 oxide

100.0 *

V. Triple Salts.

Sp. 25. *Tartrat of Potass-and-Lead.*

This triple salt may be formed by boiling tartar and oxide of lead together in water. Thenard informs us that it is insoluble, and that it is neither decomposed by alkalies nor by sulphats †.

* *Jour. de Min.* No. xxxiv. p. 760.

† Thenard, *Ann. de Chim.* xxxviii. 36.

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Sp. 26. *Muriat of Ammonia-and-lead.*

THIS triple salt may be formed by mixing together the solutions of muriat of ammonia and muriat of lead, or by boiling muriat of ammonia on oxide of lead. The solution yields no precipitate when mixed with sulphuric acid; but the alkaline carbonats throw down the lead *.

GENUS IX. SALTS OF NICKEL.

THE scarcity of nickel, and the difficulty of obtaining it in a state of purity, have hitherto prevented the possibility of an accurate examination of the combinations which its oxide forms with acids. The salts of nickel, therefore, are at present but very imperfectly known. They may be distinguished by the following properties:

Characters. 1. Its salts are in general soluble in water, and the solution has a beautiful green colour.

2. Triple prussiat of potass, when dropt into these solutions, occasions a precipitate of a dull green colour.

3. The hydrosulphuret of potass occasions a black precipitate.

4. Sulphureted hydrogen gas, according to Proust, occasions no precipitate.

5. Gallic acid, and the infusion of nut-galls, occasion a greyish white precipitate.

6. Iron, zinc, tin, manganese, or cobalt, when plun-

* Thenard, *Ann. de Chim.* xlii. 218.

ged into these solutions, occasion a precipitate of nickel in the metallic state. Chap. III.

Sp. 1. *Nitrat of Nickel.*

NITRIC ACID dissolves nickel or its oxide when assisted by heat. The solution has a bluish-green colour, and yields by evaporation nitrat of nickel in the form of rhomboidal crystals, which, on exposure to the air, at first deliquesce, but afterwards fall to powder, and gradually lose their acid, so that only the oxide of nickel remains behind *.

Sp. 2. *Muriat of Nickel.*

MURIATIC ACID dissolves nickel and its oxide slowly, and the assistance of heat is necessary. The solution, which has a green colour, yields when evaporated irregular crystals of muriat of nickel, which are decomposed by heat and by long exposure to the air, though at first they deliquesce like nitrat of nickel †.

Sp. 3. *Sulphat of Nickel.*

SULPHURIC ACID attacks nickel by the assistance of heat. When distilled over it to dryness, there remains behind a green mass soluble in water, and yielding by evaporation crystals of sulphat of nickel. This acid dissolves the oxide of nickel with facility, and yields by evaporation the same salt. The sulphat of nickel has a fine green colour, and crystallizes in decahedrons composed of two four-sided pyramids applied base to base, and truncated at their apexes ‡. Fourcroy in-

* Bergman, ii. 268. † Ibid. ‡ Ibid.

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forms us that he has seen this salt, prepared by Leblanc, crystallized in large four-sided rectangular prisms.

Sp. 4. *Phosphat of Nickel.*

Phosphoric acid is capable of dissolving only a very small portion of the oxide of nickel. The solution does not yield crystals, and has scarcely even a green colour†. Hence it would seem that the phosphat of nickel is nearly insoluble.

Sp. 5. *Carbonat of Nickel.*

It does not appear from the experiments of Bergman that carbonic acid is capable of combining with nickel directly; but when 100 parts of nickel are thrown down from their solution in acids by an alkaline carbonat, they weigh 135; whereas they weigh only 128 when thrown down by a pure alkali†. Hence we may conclude that the carbonat of nickel is composed of about . . . . . 95 oxide
5 acid

100

Sp. 6. *and* 7. *Fluat and Borat of Nickel.*

Fluoric acid dissolves nickel with difficulty, and the solution yields light green-coloured crystals‡.

Boracic acid can only be combined with nickel by mixing an alkaline borat with a solution of nickel in some acid.

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* Bergman, ii. 268. † Ibid. 392. ‡ Ibid. 268.

Sp. 8. *Acetat of Nickel.*

ACETIC ACID dissolves nickel, and forms with its oxide rhomboidal crystals of a very green colour *.

Sp. 9. *Oxalat of Nickel.*

OXALIC ACID attacks nickel at a digesting heat, and a greenish white powder is deposited, which is the oxalat of that metal. The same salt is precipitated when oxalic acid is dropt into the solution of nickel in sulphuric, nitric, or muriatic acids. It is scarcely soluble in water, and is composed, according to Bergman, of two parts of acid to one of metal †.

Sp. 10. *Tartrat of Nickel.*

TARTARIC ACID does not attack nickel ‡. The compound which it forms with its oxide has not been examined. Neither are we acquainted with any of the remainining species of the combustible salts of nickel.

Sp. 11. *Arseniat of Nickel.*

WHEN arsenic acid is digested on nickel, the metal is partly oxidized, and the arseniat of nickel separates in the form of a greenish powder scarcely soluble in water. Nickel is not precipitated from its solution in acids by arsenic acid; but when the alkaline arseniats are employed, arseniat of nickel falls in the state of a greenish-white powder §.

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* Bergman, ii. 268.
† Ibid. 269.
‡ Ibid.
§ Scheele, i. 187.

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Sp. 12. *Molybdat of Nickel.*

MOLYBDIC ACID precipitates nitrat of nickel white, provided there be no excess of nitric acid*.

Sp. 13. *Nitrat of Ammonia-and-Nickel.*

THIS triple salt, first pointed out by Thenard, is obtained by adding ammonia in excess to the nitrat of nickel. By evaporation a green coloured salt is obtained in crystals. The solution of this salt in water is not rendered turbid by alkalies; but the nickel is thrown down by hydrosulphurets †.

GENUS X. SALTS OF ZINC.

ALMOST all the acids act with energy on zinc, in consequence of the strong affinity which it has for oxygen. The salts of zinc, therefore, are very easily formed; and as the peroxide only seems to combine with acids, they are not liable to change their state, like the salts of iron and tin. They may be distinguished by the following properties:

Characters. 1. The greater number of them are soluble in water, and the solution is colourless and transparent.

2. Triple prussiat of potass occasions a white precipitate when dropt into these solutions.

3. Hydrosulphuret of potass and sulphureted hydrogen gas occasion a white precipitate.

4. Gallic acid and the infusion of nut-galls occasion no precipitate when dropt into these solutions

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* Hatchett, *Phil. Trans.* 1796. † *Ann. de Chim.* xlii. 217.

5. Alkalies occasion a white precipitate, which is readily dissolved by sulphuric or muriatic acid.

6. Zinc is not precipitated in the metallic form by any of the other metals, unless manganese be an exception.

I. Detonating Salts.

Sp. 1. *Nitrat of Zinc.*

Nitric acid attacks zinc with prodigious violence, and has been said even to inflame it. It is necessary to moderate its action by using it in a diluted state: even then considerable heat is evolved, and a strong effervescence is occasioned by the escape of nitrous oxide gas.

The solution is transparent and colourless, very caustic, and yields by evaporation flat striated tetrahedral prisms, terminated by four-sided pyramids. The specific gravity of these crystals is 2.096 *. They attract moisture when exposed to the air. They are soluble both in water and alcohol. When heated, they melt and detonate on burning coals, emitting a red flame. When distilled, they emit red vapours of nitrous acid, and assume a gelatinous form. In a strong heat, they are decomposed completely, giving out nitrous gas and oxygen gas †.

* Hassenfratz, *Ann. de Chim.* xxviii. 12.

† Fourcroy, v. 382.

II. Incombustible Salts.

Sp. 2. *Muriat of Zinc.*

Muriatic acid dissolves zinc rapidly, and with effervescence, owing to the emission of hydrogen gas. The solution is colourless; and when evaporated, does not crystallize, but assumes the form of a jelly. When distilled, a little of its acid separates, and muriat of zinc remains behind in a solid mass, easily fusible. It was formerly known by the name of *butter of zinc*. When heated, it sublimes, and is obtained in a mass of a fine white colour, composed of small needles. Its specific gravity is 1.577 *. It is very soluble in water, and when exposed to the air gradually attracts moisture, and assumes a gelatinous consistence. Sulphuric acid decomposes it, and the alkalies precipitate the oxide of zinc from its solution †.

Sp. 3. *Sulphat of Zinc.*

Concentrated sulphuric acid scarcely acts upon zinc without the assistance of heat; but if it be sufficiently diluted with water, it attacks the metal with force; hydrogen gas is emitted, and the zinc is very speedily dissolved. In this case the water is decomposed; its oxygen combines with the metal, while its hydrogen is exhaled. When the solution is sufficiently concentrated by evaporation, it yields the sulphat of zinc in crystals.

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* Hassenfratz, *Ann. de Chim.* xxviii. 13.

† Fourcroy, v. 383.

Chap. III.

History.

This salt, according to the best accounts, was discovered at Rammelsberg in Germany about the middle of the 16th century. Many ascribe the invention to Julius Duke of Brunswick. Henkel and Newmann were the first chemists who proved that it contained zinc; and Brandt first ascertained its composition completely *. It is generally formed for commercial purposes from sulphureted zinc, or blende as it is called by mineralogists. This ore is roasted, which converts the sulphur into an acid; it is then dissolved in water, and concentrated so much that, on cooling, it crystallizes very rapidly, and forms a mass not unlike loaf-sugar. This salt is usually called *white vitriol*. It is almost always contaminated with iron, and often with copper and lead. Hence the yellow spots which are visible on it, and hence also the reason that its solution in water lets fall a dirty brown sediment; a circumstance very much complained of by surgeons when they use that solution in medicine. It may be easily purified by dissolving it in water, and putting into the solution a quantity of zinc filings; taking care to agitate it occasionally. The zinc precipitates foreign metals, and takes their place. The solution is then to be filtered, and the sulphat of zinc may be obtained from it in crystals by proper evaporation.

Varieties.

There are two varieties of this salt, the *sulphat* and *supersulphat*. The sulphat crystallizes in rhomboids, differing very little from cubes †. It is colourless and perfectly transparent; its fracture is vitreous, and it re-

* Beckmann's *History of Inventions*, art. *Zinc*.

† Leblanc, *Jour. de Phys.* lv. 301.

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sembles flint glass in its appearance. Its properties have scarcely been examined.

The supersulphat is the salt which usually occurs in commerce, and which has been usually described by chemists.

Its crystals are four-sided flat prisms, terminated by quadrangular pyramids. Two opposite edges of the prism are commonly replaced by small faces, which renders the prism six-sided *. Its specific gravity when crystallized is 1.912; when in the state in which it commonly occurs in commerce, it is 1.3275 †. At the temperature of 60°, it is soluble in 2.28 parts of water; but it is much more soluble in boiling water ‡. When exposed to the air, it effloresces. When heated, it melts and speedily loses its water of crystallization, and, in a very high temperature, loses part of its acid.

The constituents of this salt are, according to

Composition.

Bergman,	Kirwan,
40	20.5 acid
20	40.0 oxide
40	39.5 water
100 §	100.0 ‖

According to Mr Smithson Tennant, the salt deprived of its water, or the *arid* salt, as he terms it, is composed of . . . . . 50 acid
50 oxide

100 ¶

* Bergman, ii. 327.
† Hassenfratz, *Ann. de Chim.* xxviii. 12.
‡ Bergman, ii. 328.
§ Ibid.
‖ Kirwan on *Mineral Waters*, Table iv.
¶ *Phil. Trans.* 1803, p. 21.

The great difference obvious in these different analyses is probably owing in part to chemists having hitherto confounded together the two varieties of this salt.

Sp. 4. *Sulphite of Zinc.*

HITHERTO the combinations which the sulphurous acid forms with metallic oxides have been examined only by Berthollet and Fourcroy and Vauquelin. To these chemists we are indebted for the discovery that the greater number of metallic sulphites are capable of combining with a quantity of sulphur, and of forming a *sulphureted sulphite*. This is the case in a remarkable degree with the sulphite of zinc.

1. *Sulphureted sulphite.* Sulphurous acid attacks zinc with considerable violence, heat is produced, and sulphureted hydrogen gas is exhaled. The solution has an acrid, astringent, sulphureous taste. When exposed to the air, it becomes thick like honey, and deposites long slender crystals in the form of four-sided prisms, terminated by four-sided pyramids. These are crystals of *sulphureted sulphite of zinc*, as Fourcroy and Vauquelin have proved. They are soluble in water and in alcohol. When exposed to the air, they become white, and deposite a white insoluble powder. Before the blow-pipe the salt swells, emits a brilliant light, and forms dendritical ramifications. When distilled, it yields water, sulphurous acid, sulphuric acid, and sulphur; and there remain behind oxide of zinc and a little sulphat of that metal. Sulphuric, nitric, and muriatic acids, when poured into its solution in water, drive off the sulphurous acid, while a quantity of sulphur precipitates. The theory of the formation of this salt is obvious. During the solution of the zinc, both

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water and sulphurous acid were decomposed; the oxygen of both combined with the metal; the hydrogen escaped combined with a portion of the sulphur of the decomposed acid, and the rest of the sulphur combined with the sulphite as it formed.

2. *Sulphite of zinc.* Sulphurous acid dissolves the oxide of zinc with the evolution of heat, but without effervescence. The solution yields crystals of sulphite of zinc. These crystals have a less acrid, but more styptic taste than sulphureted sulphite. They are less soluble in water, and more easily crystallized. They are insoluble in alcohol. When exposed to the air, they are very soon changed into sulphat of zinc; whereas the sulphureted sulphite remains long unchanged.

When a mixture of sulphur and white oxide of zinc is treated with sulphurous acid, the product is a sulphureted sulphite *.

Sp. 5. *Phosphat of Zinc.*

PHOSPHORIC ACID attacks zinc with effervescence, and dissolves it completely. The solution does not yield crystals, but leaves, when evaporated, a mass not unlike gum arabic, which before the blow-pipe melts into a transparent glass. The alkalies precipitate a white powder from this solution, which is a subphosphat of zinc, melting in a red heat to a semi-transparent glass †.

When phosphoric acid and zinc are melted together, the zinc is oxidized and phosphorus evolved ‡.

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* Fourcroy, v. 380. † Wenzel's *Verwandtschaft*, p. 172.
‡ Gren's *Handbuch*, iii. 600.

Sp. 6. *Carbonat of Zinc.*

LIQUID CARBONIC ACID, confined in a vessel with zinc or its oxide reduced to the state of a fine powder, dissolves a considerable portion of it; and the solution, when exposed to the air, is gradually covered with an iridescent pellicle of oxide of zinc *. The carbonat of zinc may be obtained in the state of a white powder, by precipitating zinc from its solution in acids by means of an alkaline carbonat.

Bergman first ascertained by analysis that this salt occurs native under the name of *calamine*. But his inferences were disputed by mineralogists, and considered by most as erroneous. Yet they have been lately fully confirmed by the precise analysis of Mr Smithson Tennant, who has demonstrated that different substances have been confounded under the name of calamine, and among others the carbonat of zinc.

Composition.

According to the analysis of Bergman, native carbonat of zinc is composed of

28 acid
66 oxide
6 water

100 †

From the analysis of Mr Smithson Tennant, it follows that *arid* carbonat is composed of

* Bergman, i. 35.

† *Opusc.* ii. 326.

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1 acid
2 oxide

3 *

When water is present, the proportion of the other constituents still continues the same. Mr Smithson has shewn, that the water in that case is combined with the oxide of zinc, constituting a hydrat, which is composed of . . . . . 3 oxide
1 water

4 †

Sp. 7. *Fluat of Zinc.*

FLUORIC ACID attacks zinc with violence, hydrogen gas is emitted, and the metal is oxidized and dissolved. The properties of the fluat thus formed have scarcely been examined ‡. The salt is said not to crystallize.

Sp. 8. *Borat of Zinc.*

BORACIC ACID scarcely attacks zinc; but it combines with its oxide, and forms with it an insoluble *borat of zinc*. This salt may be precipitated in a white powder, by pouring borat of soda into the nitrat or muriat of zinc; or by mixing boracic acid with liquid sulphat of zinc. When strongly heated, this borat becomes yellow, and is at last converted into an opaque slag §.

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* *Phil. Trans.* 1803, p. 23.
† Ibid.
‡ Scheele, i. 35.
§ Wenzel's *Verwandschaft*, p. 251.

III. Combustible Salts.

Sp. 9. *Acetat of Zinc.*

Acetic acid readily dissolves zinc, and yields by evaporation crystals of acetat of zinc, which were first mentioned by Glauber. This salt has a bitter metallic taste. Its crystals are rhomboidal or hexagonal plates, of a talky appearance. It is not altered by exposure to the air; it is soluble in water. When thrown upon live coals, it burns with a blue flame. When distilled, it yields water, an inflammable liquid, and some oil, and towards the end of the process oxide of zinc sublimes *.

This salt has been lately recommended by Mr Henry as an excellent application in cases of inflammation.

Sp. 10. *Succinat of Zinc.*

Succinic acid dissolves zinc with effervescence; and the solution yields long slender foliated crystals, the properties of which have not been examined †.

Sp. 11. *Benzoat of Zinc.*

Zinc is readily dissolved by benzoic acid. The solution yields needle-shaped crystals which are soluble in water and alcohol. When exposed to heat, their acid is volatilized ‡.

Sp. 12. *Oxalat of Zinc.*

Oxalic acid attacks zinc with a violent efferves-

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* Monnet.

† Wenzel's *Verwand*, p. 249.

‡ Trommsdorf, *Ann. de Chim.* xi. 317.

cence, and a white powder soon subsides, which is oxalat of zinc. The same salt is precipitated when oxalic acid is dropt into the solution of sulphat, nitrat, or muriat of zinc. It contains 0.75 *per cent.* of metal. This salt is scarcely soluble in water, unless there be an excess of acid *.

Sp. 13. *Tartrat of Zinc.*

TARTARIC ACID attacks zinc with effervescence, and forms with it a salt difficultly soluble in water, the properties of which have not been examined †.

Sp. 14. *Citrat of Zinc.*

CITRIC ACID attacks zinc with effervescence, and gradually deposites small brilliant crystals of citrat of zinc. They are insoluble in water, and have a styptic and metallic taste. They are composed of

50 acid
50 oxide

100 ‡

Sp. 15. *Malat of Zinc.*

MALIC ACID dissolves zinc, and yields by evaporation beautiful crystals of malat of zinc §.

Sp. 16. *Lactat of Zinc.*

LACTIC ACID dissolves zinc with effervescence, and the salt formed is capable of crystallizing ¶.

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* Bergman, i. 271. † Dijon Academicians.
‡ Vauquelin, *Fourcroy*, vii. 209.
§ Scheele, Crell's *Annals*, ii. 10. Engl. Transl. ¶ Scheele, ii. 65.

IV. Metallic Salts.

Sp. 17. *Arseniat of Zinc.*

When arsenic acid is poured upon zinc, an effervescence ensues, arsenical hydrogen gas is emitted, and a black powder precipitates, which is arsenic in the metallic state. Hence we see that the zinc deprives both a portion of water and of arsenic acid of their oxygen. When one part of zinc filings and two parts of dry arsenic acid are distilled in a retort, a violent detonation takes place when the retort becomes red, occasioned by the sudden absorption of the oxygen of the acid by the zinc. The arseniat of zinc may be precipitated by pouring arsenic acid into the acetat of zinc, or by mixing the solution of the alkaline arseniats with the sulphat of zinc. It is a white powder, insoluble in water *.

Sp. 18, 19, *and* 20.

By the same process may the tungstat, molybdat, and chromat of zinc be obtained. They also are insoluble in water: the first two are white, the last of an orange-red colour.

V. Triple Salts.

Sp. 21. *Muriat of Ammonia-and-zinc.*

When muriat of ammonia is boiled upon the white oxide of zinc, a considerable portion is dissolved; but as the solution cools, a portion of the oxide is again depo-

* Scheele, i. 181.

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sited. What remains of the solution is neither thrown down by alkalies nor their carbonats. This triple salt does not crystallize *.

Sp. 22. *Tartrat of Potass-and-zinc.*

This salt may be formed by boiling together tartar and zinc filings and water. It is very soluble in water, and not easily crystallized. No precipitation is produced in its solution by the alkalies or their carbonats †.

Sp. 23. *Sulphat of Zinc-and-iron.*

This salt may be obtained by mixing together the solutions of sulphat of iron and of zinc, or by dissolving iron and zinc together in diluted sulphuric acid. It crystallizes in rhomboids which have nearly the figure of sulphat of zinc, but its colour is a pale greeen. Its taste and solubility are nearly the same as those of sulphat of zinc. It contains a much greater proportion of zinc than iron.

Genus XI. Salts of Bismuth.

The salts of bismuth have not been examined with much attention by chemists; indeed bismuth and its combinations have been hitherto very much neglected. These salts may be distinguished by the following properties:

Characters.

1. The solution of bismuth in acids is usually colourless. When water is poured into it, a white precipi-

* Thenard, *Ann. de Chim.*

† Dijon Academicians; and Thenard, *Ann. de Chim.* xxxviii. 35.

tate immediately falls, consisting chiefly of the white oxide of bismuth.

2. Triple prussiat of potass occasions in these solutions a precipitate of a white colour, sometimes with a shade of yellow.

3. Hydrosulphuret of potass and sulphureted hydrogen occasion a black precipitate.

4. Gallic acid and the infusion of nutgalls occasion an orange-coloured precipitate.

5. When a plate of copper or tin is put into the solution of bismuth, this last metal is often precipitated in the metallic state.

Sp. 1. *Nitrat of Bismuth.*

NITRIC ACID, when concentrated, attacks bismuth with great violence, a vast quantity of nitrous gas is emitted, the metal is converted into a white oxide, much heat is evolved, and sometimes even sparks of fire, it is said, are darted out of the mixture. When the acid is diluted, the action is less violent, and the oxide of bismuth is dissolved as it forms. The solution is colourless; and on cooling lets fall crystals of a white colour, and generally attached to each other in the form of stars. They are small four-sided prisms, often terminated by four-sided summits.

This salt, when exposed to the air, attracts a little moisture, and its surface is covered with a crust of white oxide. On burning coals it detonates feebly, emitting red sparks, and leaves a yellowish powder not easily reduced. When triturated with phosphorus it detonates loudly *. When put into water it is immediately de-

* Brugnatelli, *Ann. de Chim.* xxvii. 73.

composed ; that liquid absorbing its acid, and leaving the white oxide of bismuth combined with a small portion of acid. Hence the reason that when we write upon paper with a solution of bismuth in nitric acid, the characters, at first invisible, become white when the paper is plunged into water, as Brugnatelli first observed *.

When the solution of bismuth in nitric acid is diluted with water, the greatest part of the metal separates in the state of a white oxide. In this state it was formerly known by the name of *magistery of bismuth*, and in commerce it is distinguished by the appellation of *pearl white*. To obtain it of a fine white colour, it is necessary to employ a great proportion of water, and to wash the precipitate well.

Sp. 2. *Muriat of Bismuth.*

MURIATIC ACID has scarcely any action on bismuth while cold ; but when distilled off that metal, previously reduced to powder, it gradually oxidizes, and brings it to the state of a white powder. Muriat of bismuth may be readily formed by dissolving the metal in nitro-muriatic acid, or in oxy-muriatic acid. When the solution is evaporated, it is said to yield small prismatic crystals. The muriat of bismuth, when evaporated to dryness, sublimes by the application of a moderate heat, and forms a thick concrete mass, readily melting when heated, formerly known by the name of *butter of bismuth*. It was prepared also by distilling a mixture of two parts of oxy-muriat of mercury and one part of bis-

* Brugnatelli, *Ann. de Chim.* iii. 296.

muth: an amalagam of bismuth remains in the retort, while the *butter*, as it was called, sublimes *. Chap. III.

Sp. 3. *Sulphat of Bismuth.*

SULPHURIC ACID has no action on bismuth while cold; but by the assistance of heat it converts that metal into a white oxide, while at the same time sulphurous acid is exhaled, and even sulphur sublimed, if the heat be considerable. When the saline mass, thus formed, is washed with water, almost the whole of the acid is separated, carrying along with it a very small portion of the oxide; and this lixivium yields, by evaporation, small crystals in needles, which are decomposed, and their base precipitated when any attempt is made to dissolve them in water.

Sp. 4. *Sulphite of Bismuth.*

SULPHUROUS ACID does not attack bismuth; but it combines with its oxide, and forms with it a salt insoluble in water even when assisted by an excess of acid. It has a sulphureous taste; and before the blowpipe melts into a reddish-yellow mass, which is soon reduced upon charcoal. When distilled, the acid is driven off, and the whole oxide remains in a state of purity†.

Sp. 5. *Phosphat of Bismuth.*

PHOSPHORIC ACID does not attack bismuth; but it combines with its oxide recently precipitated by an alkali. One portion of the salt formed remains in the

* Poli, *Mem. Par.* 1713. † Fourcroy, v. 204.

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state of an insoluble white powder; another portion is dissolved, and yields crystals, which do not deliquesce, and are soluble in water*. The white insoluble powder is most probably a subphosphat, and the crystals a superphosphat of bismuth.

Sp. 6, 7, 8. *Carbonat, Fluat, Borat.*

THE combinations which the oxide of bismuth forms with carbonic, fluoric, and boracic acids, have not hitherto been examined with accuracy. They may be formed by pouring into the solution of bismuth in nitric acid the alkaline carbonats, fluats, or borats. The salts required precipitate in the state of a white powder.

Sp. 9. *Acetat of Bismuth.*

ACETIC ACID has but little action on bismuth; but the acetat of bismuth may be obtained by mixing together the solutions of nitrat of bismuth and acetat of potass. When the mixture is heated, it redissolves the precipitate which had at first formed, and at the same time yields a number of thin talky crystals resembling boracic acid. Morveau, to whom we are indebted for this experiment, has ascertained also, that the addition of acetic acid deprives nitrat of bismuth of the property of affording a precipitate when diluted with water†.

Sp. 10. *Succinat of Bismuth.*

SUCCINIC ACID does not attack bismuth; but it dissolves its oxide at a boiling temperature; and the solu-

* Wenzel's *Verwandtschaft*, p. 177. † *Encyc. Method. Chim.* i. 10.

tion yields yellow crystalline plates of succinat of bismuth. According to Wenzel, the solution of this salt in water does not yield a precipitate with alkalies. It dissolves in nitric acid, and the solution is not precipitated by water*.

Sp. 11. *Benzoat of Bismuth.*

BENZOIC ACID dissolves the oxide of bismuth with facility; and the solution yields white needle-shaped crystals, which are not altered by exposure to the air, are soluble in water, and very sparingly soluble in alcohol. Sulphuric and muriatic acids decompose this salt, and heat volatilizes its acid †.

Sp. 12. *Oxalat of Bismuth.*

OXALIC ACID scarcely attacks bismuth; but it combines with its oxide, and forms with it an oxalat in the state of a white powder, scarcely soluble in water. When oxalic acid is dropt into nitrat of bismuth, small transparent polygonous grains are gradually precipitated, which possess the same properties as the white powder, and do not become opaque when put into water ‡.

Sp. 13. *Tartrat of Bismuth.*

TARTARIC ACID does not attack bismuth; but when dropt into the solution of that metal in sulphuric, nitric, or muriatic acids, tartrat of bismuth precipi-

* Wenzel's *Verwandtschaft*, p. 243.

† Trommsdorf, *Ann. de Chim.* xi. 317.

‡ Bergman, i. 261.

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tates in the state of a white crystalline powder insoluble in water*.

Sp. 14. *Arseniat of Bismuth.*

Arsenic acid oxidizes bismuth by a digesting heat; and the metal is covered with a white powder, which is arseniat of bismuth. Part also of the arseniat remains in solution, but the oxide is precipitated by the addition of water. The arseniat of bismuth precipitates when arsenic acid is poured into the nitrat of bismuth. The white powder thus obtained is difficultly fusible; but when heated with charcoal, arsenic sublimes, and the bismuth is reduced†.

Sp. 15. *Molybdat of Bismuth.*

Molybdic acid precipitates muriat of bismuth white, provided there be no excess of acid ‡.

Genus XII. Salts of Antimony.

Antimony is one of those metals whose oxides seem to combine with difficulty, and to form compounds of little permanency with acids unless there be present at the same time an alkali or an earth. This renders the investigation of the antimonial salts peculiarly difficult, and accounts for the little progress which has been made in it. Antimonial salts may be distinguished by the following properties:

Characters.

1. Their solutions are usually of a brownish yellow

* Gren's *Handbuch*, iii. 302. † Scheele, i. 84.
‡ Hatchett.

colour, and in most cases a white precipitate falls when they are diluted with water.

2. Triple prussiat of potass occasions a white precipitate when dropt into these solutions. This precipitate is merely the oxide of the metal precipitated by the water of the prussiat. When applied sufficiently concentrated, or in crystals, no precipitation takes place. In this property antimony agrees with platinum*.

3. Hydrosulphuret of potass occasions an orange-coloured precipitate.

4. Gallic acid and the infusion of nutgalls occasion a white precipitate, which is merely the oxide of the metal separated by the water of the infusion.

5. When a plate of iron or zinc is plunged into antimonial solutions, a black powder precipitates in great abundance, and very speedily when there is an excess of acid, and the solution is not too much concentrated.

I. Detonating Salts.

Sp. 1. *Nitrat of Antimony.*

Nitric acid attacks antimony slowly. Both the acid and water are decomposed, abundance of nitrous gas is emitted, and a considerable portion of ammonia is formed and combines with the acid while the metal is converted into an insoluble white oxide. A portion of the oxide is dissolved; but it does not yield crystals, and readily precipitates when the acid is diluted.

* Klaproth, Crell's *Annals*, 1798, i. 99.

II. Incombustible Salts.

Sp. 2. *Muriat of Antimony.*

Muriatic acid has no effect upon antimony at first; but the metal is gradually dissolved when it is kept long in contact with that acid. The solution is yellow, and yields by evaporation small needle-form crystals, consisting no doubt of *muriat* of antimony, or of muriatic acid combined with antimony oxidized to a minimum.

Muriatic acid dissolves the oxides of antimony with facility; but it is nitro-muriatic acid which is considered as by far the best solvent of that metal. These solutions may be considered as containing an *oxymuriat* of antimony, or muriatic acid combined with antimony oxidized to a maximum. That salt was formerly known by the name of *butter of antimony*. It was usually prepared by triturating together one part of antimony and two parts of oxymuriat of mercury, and then distilling them in a retort. At a moderate temperature the oxymuriat of antimony passes over. It is in the state of a thick fatty mass, of a greyish white colour, and often crystallized in four-sided prisms. It is exceedingly caustic, becomes coloured when exposed to the air, and melts at a very moderate temperature. When diluted with water, it is partly decomposed, and the greater part separates in the form of a white oxide. In this state it was formerly known by the name of *powder of Algoroth*.

Butter of antimony.

Sp. 3. *Sulphat of Antimony.*

SULPHURIC ACID has no action on antimony while cold; but at the boiling temperature it oxidizes that metal with effervescence, sulphurous acid is exhaled, and even sulphur sublimed, and there remains in the retort a soft white mass, evidently composed of the peroxide and sulphuric acid. Water carries off the acid and a small portion of the oxide, but leaves the greater part in the state of a white powder. When the solution is evaporated, the remainder of the oxide precipitates, so that the salt cannot be obtained in a crystalline form. The white powder may be considered as a subsulphat of antimony, for it still retains a portion of acid.

Sp. 4. *Sulphite of Antimony.*

SULPHUROUS ACID has no action on antimony while cold, but when hot it changes it into an oxide. The sulphite of antimony is precipitated in the state of an insoluble white powder when sulphurous acid is poured into the solution of antimony in muriatic acid. It has an acrid and astringent taste, melts when heated, and is volatilized and decomposed. When distilled in close vessels, it yields sulphurous acid; and there remains a reddish brown mass, consisting probably of hydrosulphuret of antimony *.

* Fourcroy, v. 231.

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Sp. 5. *Phosphat of Antimony.*

Phosphoric acid does not attack antimony; but it combines with its oxide, and even dissolves a small portion of it when assisted by heat. The solution does not crystallize, but yields by evaporation a blackish green mass, which a strong heat converts into a transparent glass*.

Sp. 6. *Carbonat of Antimony.*

Neither antimony nor its oxides are attacked by carbonic acid; neither does the precipitate of that metal weigh more when thrown down by an alkaline carbonat than when by a pure alkali †. At present, then, no such salt as carbonat of antimony is known to exist.

Sp. 7. *and* 8. *Fluat and Borat.*

Fluoric acid does not attack antimony, but with its oxide it forms a fluat not hitherto examined. Neither is the metal acted on by boracic acid, but borax precipitates the metal from acids in the state of a white powder ‡.

III. Combustible.

Sp. 9. *Acetat of Antimony.*

Acetic acid has little or no action on antimony; but it dissolves a small portion of its oxide, as Mor-

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* Wenzel's *Verwandtschaft*, p. 178. † Bergman, i. 37. ii. 39.
‡ Gren's *Handbuch*, iii. 630.

veau has shewn, and the solution, according to Wenzel, yields small crystals *. This salt is soluble in water, and was employed by Angelus Sala and some subsequent physicians as an emetic †. Chap. III.

Sp. 10. *Succinat of Antimony.*

SUCCINIC ACID does not attack antimony, but it dissolves a portion of its protoxide, and forms a salt which has not been examined.

Sp. 11. *Benzoat of Antimony.*

BENZOIC ACID readily dissolves the oxide of antimony, and the solution yields crystals, which remain dry when exposed to the air, and are decomposed by heat ‡.

Sp. 12. *Oxalat of Antimony.*

OXALIC ACID scarcely attacks antimony; but it dissolves a small portion of its oxide. The solution yields by evaporation small crystalline grains difficultly soluble in water. The same salt is precipitated by adding oxalic acid to the solution of antimony in acetic or sulphuric acid; but oxalic acid occasions no precipitate in the oxymuriat of antimony §.

Sp. 13. *Tartrat of Antimony.*

TARTARIC ACID has no action on antimony, but it dissolves a small portion of its oxides. The solution

* *Verwandtschaft*, p. 158.
† *Encyc. Method. Chim.* i. 6.
‡ Trommsdorf, *Ann. de Chim.* xi. 317.
§ Bergman, i. 271.

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scarcely crystallizes; but easily assumes the form of a jelly *.

IV. Metallic Salts.

Sp. 14. *Arseniat of Antimony.*

When arsenic acid and antimony are digested together, a white powder separates, consisting of arseniat of antimony. This powder is soluble in muriatic acid, and precipitated again by the affusion of water. The alkaline arseniats precipitate the same salt from the solution of antimony in muriatic, tartaric, or acetic acids. When a mixture of one part of antimony and three parts of arsenic acid are distilled in a retort, it enters into fusion, and then takes fire; arsenic is sublimed together with a red mass, and sulphurous acid is exhaled †.

Sp. 15. *Molybdat of Antimony.*

Molybdic acid precipitates muriat of antimony white, provided there be no excess of acid ‡.

V. Triple Salts.

Sp. 16. *Phosphat of Lime-and-antimony.*

The well-known medicine called *James's powder* has been shewn, by the analysis of Dr Pearson, to be a compound of phosphoric acid, lime, and oxide of antimony; we may therefore consider it as a triple salt. It is usually in the form of a white powder, nearly in-

* Bergman, i. 271. † Scheele, i. 184. ‡ Hatchett.

soluble in water, but partially soluble in acids. The energy with which it acts as an emetic is well known. From Dr Pearson's analysis it appears to be composed of about . . . . . 43 phosphat of lime
57 oxide of antimony

100

It may be composed by calcining in a white heat a mixture of equal parts of sulphuret of antimony and the ashes of bones *. Mr Chenevix has given the following easy formula for preparing this powder:

Dissolve in a minimum of muriatic acid equal parts of white oxide of antimony and of phosphat of lime; and pour the solution *into* a sufficient quantity of distilled water, containing pure ammonia in solution. The powder precipitates †.

Mr Chenevix considers this powder not as a compound, but a mechanical mixture of phosphat of lime and submuriat of antimony.

Sp. 17. *Tartrat of Potass-and-antimony.*

THIS salt, usually denominated *tartar emetic*, is much more employed in this country as a medicine than all the other antimonial preparations put together. It was first made known by Adrian de Mynsicht in his *Thesaurus Medico-chymicus*, published in 1631. But the preparation was in all probability suggested by a treatise, intitled *Methodus in Pulverem*, published in Italy in 1620. This book, written by Dr Cornachinus, gives an account of the method of preparing a powder which

History.

* *Phil. Trans.* 1791, p. 317. † *Phil. Mag.* xi. 110.

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had been invented by Dudley Earl of Warwick, and which had acquired great celebrity in Italy in consequence of the wonderful cures which it had performed. This powder was composed of scammony, sulphuret of antimony, and tartar triturated together. The extraordinary effects which it produced would naturally draw the attention of chemists to the combination of antimonial preparations with tartar.

Preparation.

Tartar emetic was first prepared by boiling together tartar and the *crocus metallorum* *, as it was called, in water, filtering the solution, and evaporating it till it yields crystals: glass of antimony was afterwards substituted for the crocus. But it would be needless to enumerate the various methods which have been adopted according to the fancy of different operators. These methods have been collected by Bergman, and are described by him in his treatise on *Antimoniated Tartar* †.

At present the glass of antimony, or the peroxide of antimony, are usually employed. Either of these is mixed with its own weight of tartar, and the mixture boiled in ten or twelve parts of water, till the tartar be saturated. The solution is then filtered and evaporated till a pellicle forms on its surface. On cooling it deposites regular crystals of tartar emetic. Thenard has observed, that there always remains in the solution a quantity of uncombined tartrat of potass; it ought not therefore to be evaporated too far, otherwise the

* An impure hydrosulphuret, formed by detonating in a crucible equal weights of sulphuret of antimony and nitre, and washing the residuum in water till the liquid comes off tasteless.

† *Opusc.* i. 338.

crystals of that salt will mix with those of the tartar emetic *. Chap. III.

TARTAR EMETIC is of a white colour, and crystallizes in regular tetrahedrons. When exposed to the air, it gradually loses its transparency and effloresces. It is soluble in 80 parts of cold water, and in about 40 parts of boiling water. Heat decomposes it by destroying the acid, while the potass and oxide of antimony remain behind. It is decomposed by the alkaline earths, by the alkalies and their carbonats, and by the hydrosulphurets, and several of the metals. It is decomposed also by the decoctions of plants, particularly those that are astringent and bitter, as Peruvian bark, &c. Consequently it never ought to be given in conjunction with any of these bodies. Properties.

From the analysis of Thenard, it appears that this salt is composed of

35.4	tartaric acid
39.6	oxide
16.7	potass
8.3	water
100.0	

Composition.

Or of

56.3	tartrat of antimony
35.4	tartrat of potass
8.3	water
100.0 †	

* *Ann. de Chim.* xxxviii. 39. † Ibid.

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Genus XIII. Salts of Tellurium.

Tellurium has been known for so short a time as a distinct metal, and the quantity of it hitherto examined has been so small, that the salts which it forms with acids cannot be supposed to be much known. Only the following facts have been ascertained.

The salts of tellurium may be distinguished by the following properties:

Characters. 1. Alkalies, when dropt into their solution, occasion a white precipitate, which disappears again if the alkali be added in excess.

2. Triple prussiat of potass occasions no precipitate.

3. Hydrosulphuret of potass occasions a brown or blackish precipitate.

4. The infusion of nut-galls occasions a fleaky precipitate of a yellow colour.

5. Zinc, iron, and antimony, when plunged into these solutions, occasion the tellurium to separate in the state of a black powder, which resumes its metallic brilliancy when rubbed *.

Sp. 1. *Nitrat of Tellurium.*

Nitric acid dissolves tellurium with facility. The solution is colourless, and not rendered turbid by water. It yields, when concentrated, small white, light, needle-formed dendritical crystals †.

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* Klaproth's *Beitrage*, iii. 1. and Crell's *Annals*, 1798, i. 98.
† Ibid p. 98.

Sp. 2. *Muriat of Tellurium.*

NITROMURIATIC ACID dissolves tellurium readily. The solution is transparent; but when diluted with water, it lets fall the oxide of tellurium in the state of a white precipitate, which is redissolved on adding more water. When the solution is precipitated by alcohol, and sufficiently washed, the white powder contains but a very small proportion of acid*.

Sp. 3. *Sulphat of Tellurium.*

WHEN one part of tellurium is confined with 100 parts of sulphuric acid in a close vessel, it dissolves and gives the acid a crimson colour. When water is dropt into the acid, the red colour disappears, and the metal is precipitated in black flakes. When heated, the colour equally disappears, and the metal precipitates in the state of a white powder. Diluted sulphuric acid, mixed with a little nitric acid, dissolves a considerable portion of tellurium, the solution is colourless, and no precipitate is produced in it by water†.

GENUS XIV. SALTS OF ARSENIC.

ARSENIC is capable of assuming the form of an acid, and even its white oxide has several acid properties. Hence it is more disposed to combine with metallic bases than to form salts by uniting with acids. However, as several of the acids have the property of dis-

* Klaproth's *Beitrage*, iii. 13.

† Crell's *Annals*, 1798, i. 98.

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solving it, which must be considered as a species of combination, and as the knowledge of the properties of these solutions is sometimes of importance in mineralogical investigations, it will be proper to give an account of them in this place.

The solutions of arsenic may be distinguished by the following properties:

Characters.

1. Triple prussiat of potass occasions a white precipitate when poured into solutions containing arsenic *.

2. Hydrosulphuret of potass produces a yellow precipitate, or at least gives a yellow colour to the solution.

3. Gallic acid and the infusion of nut-galls occasion scarcely any change in the solutions of arsenic.

4. The addition of water occasions a white precipitate of oxide of arsenic †, which, when heated with charcoal, emits a white smoke, having the smell of arsenic.

Sp. 1. *Nitrat of Arsenic.*

NITRIC ACID attacks arsenic with violence and converts it into white oxide, while nitrous gas is disengaged. When diluted, this acid dissolves the oxide, and deposites it again crystallized like white oxide, but really combined with nitric acid. This nitrat is scarcely soluble in water; before the blow-pipe it presents the same phenomena as sulphat of arsenic, but is dissipated more rapidly ‡.

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* The solution of arsenic in those acids which convert it into an acid, is not disturbed by the triple prussiat of potass.

† Except when the arsenic is converted into an acid.

‡ Bergman, ii. 293.

Sp. 2. *Muriat of Arsenic.*

MURIATIC ACID has scarcely any action on arsenic while cold; but when heated it dissolves it readily, at the same time a quantity of arsenicated hydrogen gas is emitted. White oxide of arsenic is also dissolved by this acid with facility, especially if a little nitric acid be mixed with it. At a boiling heat the muriatic acid dissolves about the third part of its weight of white oxide; but allows the greater part to precipitate again as the solution cools. The addition of water precipitates the greatest part of the remainder; but the muriat of arsenic, according to the experiments of Bergman, may be obtained in the state of crystals. It is very volatile, and but sparingly soluble in water *.

This salt may be formed also by triturating together equal parts of oxymuriat of mercury and oxide of arsenic, or metallic arsenic, and distilling the mixture with a moderate heat. There comes over a transparent liquor of the consistence of oil, part of which congeals in the receiver. This substance is muriat of arsenic. It was described by Lemery and others under the name of *butter of arsenic*, or *corrosive oil of arsenic*.

Sp. 3. *Sulphat of Arsenic.*

SULPHURIC ACID has no action on arsenic while cold, but when heated, sulphurous acid gas is emitted, and the metal is converted into a white oxide, a small portion only of which is retained in solution. The acid dissolves equally a small quantity of the white oxide of

* Bergman, ii. 294.

arsenic in a boiling heat, but it precipitates again as the acid cools in the form of small crystalline grains. These grains are a sulphat of arsenic. They are much less soluble in water than oxide of arsenic. Before the blow-pipe they emit a white smoke, and melt into a globule which evaporates slowly *.

Remaining Species.

Phosphat. 4. Phosphoric acid does not attack arsenic, but it dissolves its white oxide, and yields crystalline grains of phosphat, which have not been examined †.

Fluat. 5. Fluoric acid dissolves the white oxide of arsenic, and forms small crystalline grains, which have not been examined.

Borat. 6. Boracic acid combines with the white oxide of arsenic, and yields by evaporation borat of arsenic, partly in a white powder, and partly in needles ‡.

Acetat. 7. Acetic acid has no action on arsenic, but it dissolves the white oxide, and forms crystals scarcely soluble in water §.

Benzoat. 8. Benzoic acid dissolves the white oxide of arsenic, and the solution yields by evaporation very fine feather-shaped crystals, soluble in water. Their taste is acid and acrid. Alkalies occasion no precipitate in the solution of this salt. It sublimes in a moderate heat: a strong heat decomposes it ||.

Oxalat and tartrat. 9. Both oxalic and tartaric acid dissolve the white oxide of arsenic, and yield by evaporation prismatic crystals, the properties of which have not been examined ¶.

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* Bergman, ii. 293.
† Ibid. p. 295.
‡ Ibid. ii. 295.—Gren, iii. 390.
§ Ibid.
|| Trommsdorf.
¶ Bergman, ii. 295.

10. Arsenic acid dissolves the white oxide of arsenic, and yields crystalline grains scarcely soluble in water *. Chap. III. Arseniat.

The remaining salts of arsenic are entirely unknown.

Genus XV. Salts of Cobalt.

The salts of cobalt have attracted the attention of chemists, in consequence of the property which some of them have of changing their colour when heated, and thus forming what has received the name of *sympathetic ink*; an appellation given to all liquids, the characters formed by which are colourless and invisible when written upon paper, but become visible and coloured by undergoing certain processes; and likewise to those liquids which form characters upon paper susceptible of changing their colour by certain processes. It is probable that chemists have not hitherto had an opportunity of often examining the pure salts of cobalt; for several of the other metals adhere to cobalt with such persevering obstinacy, that it is very difficult to obtain it in a separate state. The salts of cobalt may be distinguished by the following properties:

1. The greater number of them are soluble in water, and the solution has a reddish or brownish colour, at least when diluted. Characters.

2. The alkalies, when dropt into these solutions, occasion a blue-coloured precipitate, and sometimes a reddish-brown.

3. Triple prussiat of potass occasions a brownish-yellow precipitate, often with a shade of blue.

4. Hydrosulphuret of potass occasions a black precipi-

* Bergman, ii. 295.

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tate, soluble again if the hydrosulphuret be added in excess. According to Proust, sulphureted hydrogen gas occasions no precipitate in these solutions *.

5. Gallic acid produces no change; but the tincture of nutgalls occasions a yellowish-white precipitate.

6. Cobalt is not precipitated from its solution in acids by zinc.

Sp. 1. *Nitrat of Cobalt.*

NITRIC ACID attacks cobalt when assisted by heat. The solution has a red colour, and yields by evaporation small prismatic crystals of a red colour, deliquescent in the air, and decomposed by heat, leaving a deep red powder.

Sp. 2. *Muriat of Cobalt.*

MURIATIC ACID acts with difficulty upon cobalt even when assisted by heat. But a solution may be readily obtained by adding a little nitric acid. Muriatic acid dissolves the peroxide of cobalt with an effervescence, occasioned by the emission of oxymuriatic acid gas. The solution, when concentrated, is of a fine green, but it becomes red when diluted with water. This solution, when sufficiently concentrated, yields small deliquescent crystals of muriat of cobalt.

Sympathetic ink.

The solution of this salt constitutes the first and best known of all the sympathetic inks. It is diluted with water till its colour almost disappears; and then the characters written with it on paper are invisible while cold, but if the paper be gently heated they acquire a acquire a fine green colour, which disappears again

* *Ann. de Chim.* xxxv. 54.

when the paper cools. This may be repeated as often as we please, provided care be taken not to heat the paper too much, otherwise the characters acquire a permanent brown colour. Klaproth affirms, that this change to green only takes place when the cobalt-solution is contaminated with iron: if the cobalt be pure, the characters, instead of a green, acquire a blue colour when heated *. This sympathetic ink was first made known by Waitz in 1705 †; it was described a second time by Teichmeyer in 1731 ‡; and a third time by Hellot in 1737 §. The cause of this singular change of colour has not hitherto been explained in a satisfactory manner. It takes place equally in close vessels; so that it can scarcely be ascribed to the action of the air or of moisture. At present it is supposed, but without any direct proof, to be owing to the partial deoxidizement of the oxide of cobalt by heat, and its reabsorption of oxygen when cold.

But this supposition is not likely to be verified. Thenard has observed with justice, that the appearance of the green colour, when the paper is heated, is owing to the concentration of the solution; and its disappearing, when cold, to its dilution, by absorbing again the moisture it had lost ||. It is therefore exactly similar to the change of the solution from green to red when diluted with water; but the reason of this change remains still to be assigned.

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* Klaproth's *Observations on the Fossils of Cornwall*, p. 64. Eng. Trans.
† See Wiegleb's *Geschichte*, i. 126.
‡ *Commerc. Litterarum*, p. 91.
§ *Mem. Par.* 1737.
|| *Ann. de Chim.* xlii. 214.

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Sp. 3. *Sulphat of Cobalt.*

SULPHURIC ACID requires a boiling heat before it can attack cobalt: sulphurous acid gas is disengaged, and a brownish-red mass remains, which dissolves with facility in water. Sulphuric acid dissolves the peroxide of cobalt with difficulty; bubbles of gas are emitted during this solution, which Thenard supposes to be oxygen *. The solution is always red; and yields by evaporation small needle-form crystals, consisting of rhomboidal prisms, terminated by dihedral summits. This salt has a reddish colour. It is soluble in 24 parts of water, but insoluble in alcohol †. When heated it melts, swells up, and is decomposed, leaving the oxide of cobalt of a deep blue colour. It is decomposed also by alkalies, which precipitate its base in the form of a flesh-coloured powder.

Remaining Species.

Phosphat. 4. PHOSPHORIC ACID does not attack cobalt; but it dissolves its oxides, and forms a deep wine-red solution ‡.

5. The fixed alkaline carbonats precipitate cobalt from its solutions in the state of reddish-blue powder. This insoluble carbonat contains, according to Bergman, $\frac{1}{8}$ of its weight of carbonic acid §.

Fluat. 6. Fluoric acid does not attack cobalt, but it dissolves its oxide, and forms with it a yellow-coloured gelatinous solution ‖.

Borat. 7. Boracic acid does not act upon cobalt, but it pre-

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* *Ann. de Chim.* xlii. 211.

† Gren's *Handbuch*, iii. 524.

‡ Ibid. iii. 528.

§ *Opusc.* ii. p. 388. and 392.

‖ Scheele, i. 35.

cipitates that metal from its solution in other acids in the state of a reddish-white powder. This borat is scarcely soluble in water. When heated it melts into a deep blue glass *. Chap. III.

8. Acetic acid dissolves the oxide of cobalt with facility. The solution does not crystallize; and when evaporated to dryness, soon deliquesces again. It has a fine red colour while cold, but becomes blue when heated †. This solution forms a sympathetic ink: the characters drawn in it are colourless while cold, but become blue when heated ‡. Acetat.

9. Oxalic acid attacks cobalt, and converts it into a red powder, which is oxalat of cobalt. This salt is insoluble in water, but it dissolves in an excess of acid, and yields crystals. Oxalic acid precipitates an oxalat of cobalt from the solution of that metal in most acids §. Oxalat.

10. Tartaric acid dissolves the oxide of cobalt, and forms a red solution, which yields crystals ‖. Tartrat.

11. Arsenic acid, when digested upon cobalt, acquires a red colour, but it does not dissolve the metal completely. Arsenic acid does not precipitate cobalt from its solution in acids; but the alkaline arseniats occasion a precipitate of a fine red colour, which is arseniat of cobalt ¶. This salt is found native; sometimes in the state of a fine red efflorescence, and sometimes crystallized in small four-sided prisms or tables. Arseniat.

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* Wenzel's *Verwandtschaft*, p. 258.
† Ibid. p. 150.
‡ Ilseman, *Crell's Annals*, 1785. ii. 25.
§ Bergman, i. 270.
‖ Gren, iii. 128.
¶ Scheele, i. 186.

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Sp. 12. *Nitrat of Ammonia-and-cobalt.*

When a solution of cobalt in nitric acid is supersaturated with ammonia, it is well known that no precipitate appears. When this solution is evaporated to dryness, and the residue is treated with water, a red solution is obtained, which yields by slow evaporation regular cubes of a red colour. These crystals are a triple salt, composed of nitric acid, ammonia, and oxide of cobalt. They were first observed by Thenard. Their taste is urinous; they are not altered by exposure to the air. When heated they burn with a yellowish-white flame, like nitrat of ammonia, leaving an oxide of cobalt. Their solution in water is neither precipitated by alkalies nor alkaline earths. But when boiled with potass, ammonia is disengaged, and the oxide of cobalt precipitates *.

Genus XVI. Salts of Manganese.

All the properties of this genus of salts with which we are even at present acquainted were ascertained by Bergman and Scheele, by whose labours the oxide of manganese, one of the most important of all our instruments, was first put into the hands of chemists. The salts of manganese may be distinguished by the following properties:

Characters. 1. They are almost all soluble in water; and the solution, when treated with fixed alkalies, deposites a white

* Thenard, *Ann. de Chim.* xlii. 245.

or reddish coloured precipitate, which very soon becomes black when exposed to the air.

2. Triple prussiat of potass occasions a yellowish-white precipitate when dropt into these solutions.

3. Hydrosulphuret of potass occasions a white precipitate. Sulphureted hydrogen gas gives the solution a whiter colour, but produces no precipitate.

4. Gallic acid occasions no precipitate.

5. Manganese is not precipitated from its solution in the metallic state by any of the other metals.

Sp. 1. *Nitrat of Manganese.*

NITRIC ACID dissolves manganese with effervescence, occasioned by the emission of nitrous gas. It dissolves the white oxide with facility, and without the emission of any gas: but it has very little action on the black oxide; however, by very long digestion, it at last dissolves a part of it. The solution goes on much more rapidly if a little sugar or gum, or any similar substance, be added, and at the same time a quantity of carbonic acid gas is emitted. Hence we see that the black oxide must part with a portion of its oxygen before nitric acid can dissolve it. Nitrous acid acts upon the black oxide much more readily, and is converted entirely into nitric acid. The solution, in what manner soever it has been made, is always colourless, provided the manganese be pure. Hence we may conclude that it contains only the white oxide. So that, as far as is known at present, there is no such substance as *oxy-nitrat* of manganese. This solution does not crystallize how slowly soever it be evaporated. Heat decomposes it, and leaves the oxide *.

* Scheele, i. 43. 64; and Bergman, ii. 216.

Sp. 2. *Muriat of Manganese.*

MURIATIC ACID readily dissolves manganese with an efferyescence occasioned by the emission of hydrogen gas. It dissolves the white oxide without effervescence, and the solution is colourless. When allowed to remain cold upon the black oxide, it dissolves a portion of it, and forms a red solution, which deposites red oxide when diluted with water. When heat is applied to the mixture of black oxide of manganese and muriatic acid, an effervescence takes place, and oxymuriatic acid gas is emitted. The oxide becomes white and gradually dissolves. In this case the acid is divided into two portions; one absorbs oxygen from the metal, and flies off in the state of gas; the other dissolves the white oxide, as it is set at liberty by the decomposition of the black oxide. If sugar or any other similar vegetable substance is added, no oxymuriatic gas is emitted, but instead of it carbonic acid gas. From these facts it is obvious that muriatic acid combines both with the white and red oxides of manganese; so that there is both a *muriat* and *oxymuriat* of that metal. But the properties of these salts are still almost unknown. According to Bergman, the muriat crystallizes with difficulty, and when evaporated to dryness yields a saline mass, which attracts moisture. The solution of the oxymuriat is red, and it seems to be partly decomposed by water *.

Sp. 3. *Sulphated Manganese.*

SULPHURIC ACID acts with energy on manganese,

* Bergman, ii. 217.—Scheele, i. 46 and 67.

especially when diluted with two or three times its weight of water, and forms with it a colourless solution. It dissolves also with equal facility the white and red oxides of manganese; but it has no action whatever on the black oxide unless assisted by heat. When that is the case, oxygen gas passes off in abundance, and the oxide is dissolved. The same solution takes place without the emission of that gas when a little sugar is added to the mixture. Hence we see that the black oxide is incapable of combining with sulphuric acid, since it always loses a portion of its oxygen before solution. But Bergman has shewn, that both the white and the red oxide combine with that acid, and form with it a salt. So that we have two combinations of sulphuric acid and manganese: first, the combination of sulphuric acid and the white oxide, which form *sulphat* of manganese; and, secondly, the combination of the acid with the red oxide, which constitutes *oxysulphat* of manganese.

1. *Sulphat of manganese.* This salt is obtained pure by dissolving manganese in diluted sulphuric acid, or by dissolving the black oxide in that acid, adding at the same time a little sugar. The solution is colourless, and yields by evaporation transparent rhomboidal crystals of sulphat of manganese. These crystals have a very bitter taste, and are decomposed by heat, which drives off their acid. Alkalies precipitate from them the manganese in the state of a white oxide *.

2. *Oxysulphat of manganese.* This salt may be obtained by distilling sulphuric acid from the black oxide of manganese, and washing the residuum in water. A

* Bergman, ii. 210.

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red or rather violet coloured liquid is thus obtained, which holds in solution the oxysulphat of manganese. This solution is difficultly crystallized, but passes readily into a gelatinous form. The few crystals which are mixed with this jelly are soft, and have but little permanency. When evaporated to dryness, it yields thin red coloured saline crusts, which precipitate successively from the surface, and which do not readily deliquesce. This salt is very soluble in water; and alkalies precipitate the manganese in the state of a red oxide, which soon becomes black when exposed to the air *.

Sulphurous acid readily dissolves the black oxide of manganese, and forms with it sulphat of manganese, as Scheele ascertained †. The theory of this is obvious. Part of its oxygen is abstracted from the manganese by the acid; in consequence of which, the black oxide is converted into white oxide, and the sulphurous into sulphuric acid. It is not known whether sulphurous acid forms with the oxides of manganese a permanent salt.

Sp. 4. *Phosphat of Manganese.*

PHOSPHORIC ACID has but little action on manganese or its oxides, because it forms with them a salt difficultly soluble in water. But phosphat of manganese may be obtained in the form of a precipitate, by mixing an alkaline phosphat with the solution of manganese in any of the three mineral acids ‡. This salt has not been hitherto examined.

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* Bergman, p. 215.

† Scheele, i. 43.

‡ Ibid. i 48.—Bergman, ii. 219.

Sp. 5. *Carbonat of Manganese.*

LIQUID CARBONIC ACID attacks manganese or its black oxide, and dissolves a small portion. When the solution is exposed to the air, the acid gradually escapes, and a white pellicle forms on its surface, consisting of white oxide. During the solution of manganese in this acid, an odour similar to that of burning fat is perceptible *.

Sp. 6. *and* 7. *Fluat and Borat of Manganese.*

THE fluoric and boracic acids form likewise with the oxides of manganese salts difficultly soluble in water, the properties of which have not hitherto been much examined. These acids have but little action on manganese and its oxides; but the fluat or borat of manganese may be easily formed by pouring the alkaline fluats or borats into sulphat or muriat of manganese.

Remaining Species.

8. ACETIC ACID has but little effect upon manganese immediately; but it dissolves a small portion by long digestion, as it does also of the black oxide. The solution does not yield crystals, and when evaporated to dryness soon deliquesces again †. Vauquelin has employed acetic acid in order to separate iron from manganese. When a mixture of these two metals is dissolved in acetic acid, and the solution evaporated to dryness, the acid adheres to the manganese, but abandons the iron. Water dissolves the acetat of manganese, but Acetat.

* Bergman, i. 35; and Scheele, i. 51. † Bergman, ii. 249.

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leaves the oxide of iron on the filter. Two or three evaporations and solutions are sufficient to deprive acetat of manganese of the whole of its iron *.

Benzoat. 9. Benzoic acid dissolves the white oxide of arsenic with facility. The solution yields small crystalline scales easily soluble in water, but sparingly in alcohol. They are not altered by exposure to the air †.

Oxalat. 10. Oxalic acid attacks manganese, and dissolves the black oxide with effervescence. The solution, when saturated, lets fall the oxalat of manganese in the state of a white powder. Oxalic acid precipitates the same powder from the solution of manganese in sulphuric, nitric, or muriatic acid ‡.

Tartrat. 11. Tartaric acid dissolves black oxide of manganese cold; but the solution is blackish: when heated, an effervescence ensues, owing to the decomposition of part of the acid and the escape of carbonic acid gas, and the solution becomes colourless. Tartrat of potass precipitates a tartrat of manganese from the solution of that metal in any of the three mineral acids §.

Citrat. 12. Citric acid acts upon the black oxide of manganese exactly as tartaric acid ‖.

Arseniat. 13. Arsenic acid dissolves the white oxide of manganese with facility; and when it approaches the point of saturation, the solution becomes thick, with small crystals, which separate. These crystals are arseniat of manganese. They are precipitated when an alkaline arseniat is dropt into the solution of manganese in an acid. These crystals do not melt when heated, neither

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* *Ann. de Chim.* xli. 249.
† Trommsdorf, Ibid. xi. 37.
‡ Bergman, i. 272. and ii. 219.
§ Ibid. ii. 219.
‖ Ibid. ii. 220

does arsenic sublime, unless charcoal be mixed with them *. Chap. III.

GENUS XVII. SALTS OF TUNGSTEN.

THIS genus of salts is altogether unknown; the scarcity of tungsten, and the difficulty of obtaining it in a state of purity, having hitherto prevented the possibility of attemping to ascertain the compounds which its oxides are capable of forming with acids. Indeed it has not been demonstrated that the oxides of tungsten are capable of combining with acids and forming salts.

Neither sulphuric nor muriatic acids seem capable of altering the metal; but nitromuriatic acid attacks it at a boiling heat, and nitrous gas is emitted *.

GENUS XVIII. SALTS OF MOLYBDENUM.

THIS genus is still as problematical as the last. Indeed it has been ascertained that the oxides of molybdenum are incapable of forming crystallizable salts with acids. But many acids dissolve them; and the resulting solutions are remarkable for the changes of colour to which they are liable.

1. It does not appear that nitric acid dissolves the oxides of molybdenum; but it converts them all into molybdic acid. Nitrat.

2. Muriatic acid dissolves the oxide of molybdenum in a boiling heat, and the solution assumes a deep blue Muriat.

* Scheele, i. 188.

† Vauquelin and Hecht, *Jour. de Min.* No. xix. p. 25.

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colour, and a blue sediment falls. Muriatic acid dissolves likewise molybdic acid. The solution is of a pale yellowish green colour, but becomes blue when saturated with potass *.

Sulphat. 3. When diluted sulphuric acid is digested on molybdic oxide, a solution takes place, which is green while hot, but becomes blue on cooling †. Sulphuric acid dissolves molybdic acid by the assistance of heat. The solution is colourless while hot; but on cooling it assumes a deep blue colour, which is heightened by saturating the solution with soda ‡.

Phosphat. 4. Phosphoric acid dissolves molybdic oxide when assisted by heat. The solution has a blue colour §.

Fluat. 5. Fluoric acid likewise dissolves the oxides of molybdenum. The solution, while hot, is greenish yellow; when concentrated by evaporation, it becomes yellow; and when reduced to a dry mass, greenish blue. When this mass is well washed, it assumes a fine green colour: the water employed acquires a dirty grass green ‖.

Borat. 6. Liquid boracic acid does not attack the oxides of molybdenum ¶.

Acetat. 7. Acetic acid, when digested on molybdic oxide, assumes a deep blue colour, and yields a blue powder when evaporated to dryness **.

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* Hatchett.

† Ilseman; as quoted by Gren, *Handbuch*, iii. 711.

‡ Hatchett, *Phil. Trans.* 1795, p. 123.

§ Gren's *Handbuch*, iii. 713.

‖ Heyer, Crell's *Annals*, 1787, ii. 121.

¶ Gren's *Handbuch*, iii. 713.

** Ibid.

8. Benzoic acid acts upon the oxides of molybdenum precisely as acetic acid *. Chap. III. Benzoat.

9. Oxalic forms a blue solution with molybdic oxide, which does not change colour by evaporation. But when diluted with water, it becomes green: a large addition renders it brown†. Oxalat.

10. Tartaric acid dissolves molybdic oxide when assisted by heat: the solution is blue; and when evaporated to dryness, leaves a pale blue mass ‡. Tartrat.

11. The oxide of molybdenum is precipitated brown from acids by triple prussiat of potass; and deep brown by tincture of nut-galls §. Molybdat.

Genus XIX. Salts of Uranium.

This genus of salts has been hitherto examined only by Klaproth and Richter. The salts of uranium may be distinguished by the following properties:

1. The greater number of them are soluble in water, and the solution has a yellow colour. Characters.

2. The pure alkalies occasion in these solutions a yellow precipitate; the alkaline carbonats a white precipitate, soluble in an excess of alkali.

3. Triple prussiat of potass occasions a brownish-red precipitate, which does not assume the form of flakes like the prussiat of copper.

4. Hydrosulphuret of potass occasions a brownish-yellow precipitate.

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* Gren's *Handbuch*, iii. 317.

† Heyer, Crell's *Annals*, 1787, ii. 121.

‡ Ibid. § Gren's *Handbuch*, iii. 713.

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5. The infusion of nut-galls occasions a chocolate-coloured precipitate.

6. No precipitate is occasioned by zinc, iron, or tin *.

Nitrat. *Sp.* 1. Nitric acid dissolves the oxide of uranium with facility, and the solution yields, when evaporated, large crystals of nitrat of uranium of a beautiful yellowish-green colour, and in the form of hexagonal tables, which effloresce in the air †.

Muriat. 2. Muriatic acid forms with oxide of uranium deliquescent crystals of a yellowish-green colour, and in the form of four-sided tables ‡.

Sulphat. 3. Sulphuric acid, when diluted, readily dissolves the yellow oxide of uranium, and the solution yields by evaporation fine orange-coloured prisms of sulphat of uranium §.

Phosphat. 4. Phosphoric acid forms with oxide of uranium yellowish-white flakes, scarcely soluble in water. The salt may be precipitated by adding phosphoric acid to the acetat of uranium ‖.

Fluat. 5. Fluoric acid dissolves the yellow oxide, and forms with it crystals which do not deliquesce.

Acetat. 6. Concentrated acetic acid dissolves oxide of uranium by digestion, and yields beautiful yellow crystals in the form of long, slender, transparent, four-sided prisms, terminated by four-sided pyramids. When heated gradually, the acid is decomposed and driven off, but the remaining oxide still retains the form of the crystals ¶.

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* Klaproth, Crell's *Annals*, i. 130. Eng. Transl.—Richter's *Neuern Gegenstande*.—Gren's *Handbuch*, iii. 741.

† Klaproth, Crell's *Annals*, i. 130. Eng. Transl.

‡ Ibid. § Ibid. ‖ Ibid. p. 135. ¶ Ibid.

7. Tartaric acid forms with the oxide of uranium a salt scarcely soluble in water. Chap. III. Tartrat.

8. When an alkaline arseniat is dropt into nitrat of uranium, the arseniat of uranium precipitates in the state of a yellowish-white powder. Arseniat.

9. and 10. The tungstat and molybdat of uranium may be obtained by a similar process. The first is a brownish-white powder, insoluble in water; the second is whitish-yellow, and difficultly soluble.

Richter formed also the borat, oxalat, citrat, malat, benzoat, succinat, and sebat of uranium; but the properties of these salts have not been described.

Genus XX. Salts of Titanium.

For all that is at present known respecting this genus of salts, we are indebted to the experiments of Gregor, Klaproth, Vauquelin, and Hecht. The salts of titanium may be distinguished by the following properties:

1. They are in general colourless, and in some degree soluble in water. Characters.

2. The alkaline carbonats occasion in these solutions a white flaky precipitate.

3. Triple prussiat of potass occasions a grass-green precipitate mixed with brown. When an alkali is dropt in after the prussiat, the precipitate becomes purple, then blue, and at last white.

4. Hydrosulphuret of potass occasions a dirty glass-green precipitate. Sulphureted hydrogen gas occasions no precipitate.

5. The infusion of nut-galls occasions a very bulky

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reddish-brown precipitate. If the solution is concentrated, it assumes the appearance of curdled blood.

6. When a rod of tin is plunged into a solution of titanium, the liquid around it gradually assumes a fine red colour. A rod of zinc, on the other hand, occasions a deep blue colour*.

Nitrat.

Sp. 1. Nitric acid has no action on the red oxide of titanium, and scarcely any upon the metal; but it dissolves the carbonat, provided heat be applied; and the solution yields, by evaporation, transparent crystals, in the form of elongated rhombs, having two opposite angles truncated, so as to represent six-sided tables. According to Vauquelin and Hecht, this solution only succeeds when the metal is combined with a minimum of oxygen.

Muriat.

2. Muriatic acid dissolves titanium; but it has no effect upon its red oxide. The carbonat of titanium is readily dissolved by this acid; and the solution, according to Klaproth, yields transparent cubic crystals. According to Vauquelin and Hecht, the solution is yellow, and assumes the form of a jelly when evaporated. Heat occasions the emission of oxymuriatic acid, and the oxide precipitates, and is no longer soluble in muriatic acid, unless it be boiled in nitric acid. Hence they conclude, that the muriat contains titanium combined with a maximum of oxygen, and that the suboxide is incapable of uniting with muriatic acid.

Sulphat.

3. Boiling sulphuric acid oxidizes titanium, and dissolves a small portion of it; but on the red oxide of ti-

* Klaproth's *Beitrage*, i. 233.

tanium that acid has no action whatever. It dissolves the carbonat of that metal with effervescence, occasioned by the emission of carbonic acid. The solution, when evaporated, is converted into a white opaque gelatinous mass. Chap. III.

4. and 5. When the phosphoric or arsenic acid is dropt into the solution of titanium in acids, it occasions a white precipitate.

6. When one part of red oxide of titanium and six parts of carbonat of potass are melted together in a crucible, the mass, when washed sufficiently with water, leaves a white powder, with a slight red tinge, which Vauquelin and Hecht have ascertained to be carbonat of titanium. According to the experiments of these chemists, it is composed of Carbonat.

75 white oxide
25 carbonic acid

100

7. and 8. Oxalic and tartaric acids likewise occasion a white precipitate, but it is redissolved again almost as soon as formed *.

Genus XXI. Salts of Chromium.

This genus of salts is still altogether unknown, the small quantity of chromium hitherto obtained not having permitted chemists to examine the combinations which its oxides are susceptible of forming with acids.

* *Jour. de Min.* No. xv. p. 1.

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But the presence of this metal in solution may be ascertained by the following properties:

Characters.

1. Triple prussiat of potass occasions a green precipitate.

2. The infusion of nut-galls occasions a brown precipitate.

3. The hydrosulphuret of potass occasions a green precipitate, which a few drops of nitric acid change to yellow.

Genus XXII. Salts of Columbium.

The scarcity of this metal having prevented Mr Hatchett, the discoverer, from multiplying his experiments on it, we are not to expect many facts respecting the combination of its oxides with acids. The salts of columbium may be distinguished by the following properties:

Characters.

1. Their solutions, as far as known, are transparent and colourless.

2. Alkaline carbonats occasion a white flaky precipitate in these solutions.

3. Triple prussiat of potass changes them to an olive green, and occasions a beautiful olive-coloured precipitate.

4. Hydrosulphuret of ammonia occasions a reddish chocolate coloured precipitate.

5. Tincture of nut-galls throws down a very high orange-coloured precipitate.

6. A rod of zinc throws down a white flaky precipitate.

Mr Hatchett, to whom we are indebted for all the facts known belonging to this genus of salts, has ren-

dered it probable that there are several oxides of columbium; but nothing has been ascertained respecting the particular oxides which combine with acids. Chap. III.

1. Nitric acid is incapable of dissolving the oxides of columbium. It seems to have the property of converting the white oxide into columbic acid. Nitrat.

2. Boiling muriatic acid dissolves columbic acid. The solution is colourless, and may be diluted with water without any change being produced. When the solution was evaporated to dryness, it left a pale yellow substance, insoluble in water, and difficultly soluble in muriatic acid. Muriat.

3. Boiling sulphuric acid dissolves columbic acid, and forms a transparent colourless solution. When largely diluted with water, this solution becomes milky, and deposites a white precipitate. When allowed to dry, this precipitate cracks, and becomes first lavender-blue, and afterwards brownish grey. It is a subsulphat of columbium, and in a boiling temperature is slightly soluble in muriatic acid and in potass ley. The diluted sulphuric acid solution still retains a supersulphat of columbium. Sulphat.

4. When phosphoric acid is added to the concentrated solution of columbium in sulphuric acid, the whole assumes the form of an opaque white stiff jelly insoluble in water. From muriat of columbium phosphoric acid throws down a white flocculent powder. Phosphat.

5. Acetic acid has no effect on columbic acid *.

* Hatchett on "A Mineral Substance from North America." *Phil. Trans.* 1802.

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Genus XXIII. Salts of Tantalium.

Eckeberg affirms that the oxide of tantalium is completely insoluble in acids; of course this genus of salts does not exist.

SECT. III.

REMARKS ON THE SALTS.

Such are the properties of all the salts which have been hitherto examined by chemists, and which amount to about six hundred. Great as this number is, it cannot be doubted that the class of salts will be considerably increased hereafter.

Importance of the salts.

Of these bodies, there are some, as alum, copperas, &c. which constitute the basis of different arts and manufactures, and which therefore are of sufficient importance to deserve an accurate examination even on their own account. Others, again, are the source from which chemists obtain many of the most valuable of their instruments of analysis; as nitre, common salt, phosphat of lime, sal ammoniac, sulphat of barytes, &c. and therefore naturally claim the particular attention of all those who cultivate the science. But it must be allowed, that by far the greater number of saline bodies are at present of no apparent use whatever, either in the arts or in chemistry. At first sight it may appear a very useless piece of labour to be at the trouble of

examining and describing these; but there are several reasons which render a precise knowledge of all the salts not only proper but even necessary.

Were we to limit ourselves to the examination of those things whose usefulness is already known, there would be an end of all improvement. Every thing must be useless, as far as regards us, till its properties be known, and the purposes to which it may be applied ascertained. Many of those salts which we at present consider as of no utility, may hereafter be found of the greatest consequence, when their properties have been more completely investigated. This remark has been verified more than once within these few years. The muriat of lime, for instance, was formerly thrown away, but is now applied with great advantage to produce artificial cold; and the hyperoxymuriats, though a new class of salts, constitute an essential ingredient in the process of bleaching. Want of utility therefore is but a meagre reason for neglecting the examination of the salts, unless it could be demonstrated *a priori* that they never can be applied to any use.

But were we even certain that this were the case, still the examination of a great number of these salts would be indispensable: For those salts which are the most useful are seldom or never found in a state of purity; they are constantly mixed and contaminated with other salts, from which it is necessary to free them before they will answer the purposes to which they are usually applied. Now these foreign salts cannot be separated unless we be acquainted with them, at least sufficiently to know the effect of different agents upon them; that is, unless we be acquainted with their properties. Thus we see that it is not possible to obtain

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those salts which are really useful, without at the same time knowing the nature of many salts which have been applied to no use. Thus common salt is always mixed with muriat of magnesia, and cannot be obtained unless we understand the method of separating or decomposing that salt.

But it is not strictly true that many of the salts are altogether useless. It may be affirmed, with the greatest truth, that, even at present, there is not one among them, the knowledge of whose properties is not of some advantage. One of the most important and difficult things in chemistry is to ascertain exactly the nature and composition of different bodies. Now this can only be done by observing the changes produced upon them by other bodies, and the compounds which they are capable of forming. Thus if, on examining a substance, I find, that when, combined with sulphuric acid, it forms a heavy insoluble white powder; with muriatic acid, a very soluble salt, which crystallizes in tables, and is insoluble in alcohol; with phosphoric and oxalic acid likewise an insoluble powder, &c.—I conclude, without hesitation, that it is barytes. A substance which dissolves in sulphuric acid, and forms a salt of a blue colour, crystallized in rhomboidal prisms, of an acrid taste and caustic, which forms with muriatic acid a green salt, which becomes blue when mixed with ammonia, and which when mixed with alkalies occasions a blue or green precipitate—I conclude to be copper. Thus it is the knowledge of the salts which the different alkalies, earths, metals, and acids, are capable of forming, which enables us to discover their presence when they enter as ingredients into different compounds. Here, then, is a reason for studying the properties of

the salts, independent of their utility as individual bodies; and it may be affirmed with truth, that chemical skill is in every case proportional to the extent of this knowledge.

The great number of saline bodies renders it a difficult task to remember the properties of each. Indeed the thing would be impossible, were it not that the salts naturally arrange themselves into certain groups, the individuals belonging to which all agree in certain general properties which may be remembered with facility; and after these general properties have indicated the group to which a given salt belongs, it is much easier to ascertain the species.

Salts divided into two Classes.

The salts may be divided conveniently into two classes, under one or other of which every salt is to be placed. These two classes constitute the two first Sections of this Chapter. The first class comprehends under it all the earthy and alkaline salts; the second class all the metalline salts.

First Class,

The first class may be distinguished by the following characters: The salts belonging to it are, either, 1. Soluble in water; and in that case the solution is not precipitated by hydrosulphuret of potass *, triple prussiat of potass †, or infusion of nut-galls ‡: or, 2. Insoluble in water; and in that case they are either soluble in muriatic acid, or become so when heated to redness, or fused with carbonat of potass; and the solution yields a precipitate when sulphuric acid is added, or if not, at least when potass is added. The insoluble salts

* Except salts with base of alumina or zirconia.

† Except salts with base of yttria or zirconia.

‡ Except salts with base of yttria, glucina, or zirconia.

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afford with borax, before the blow-pipe, a white glass or enamel.

Divided into two orders.

As the salts belonging to this class are very numerous, it has been divided into two orders. The salts belonging to the first order are incombustible when suddenly heated to redness *. Those belonging to the second order contain combustible acids; and when suddenly heated, either burn partially, leaving incombustible salts behind them, or the acid is totally decomposed and drawn off, leaving the base mixed with charcoal. The first order contains 13 genera, the second contains 17. The characters by which each of these genera may be distinguished have been given in the first Section of this Chapter, and need not be repeated here. Having found the genus to which any salt belongs, the species is to be ascertained by a careful examination of the properties described as belonging to each. But the investigation will be much facilitated by attending to the following observations:

1. The species may be distinguished into two kinds; those whose base is an *alkali*, and those which have an *earthy* base.

2. The alkaline salts are all soluble in water. Potass occasions no precipitate of a white powder when added to the solution; neither does oxalic acid occasion any precipitate.

3. The salts with an ammoniacal base are all either dissipated entirely, or converted into an acid when exposed to a red heat.

4. Many of the earthy salts are insoluble in water; a

* Except nitrat of ammonia and hyperoxymuriat of ammonia.

white powder is precipitated from the soluble salts either by the addition of potass or of sulphuric acid.

5. The salts whose base is barytes are all * insoluble in water, or nearly so, except six; namely, the nitrat, muriat, acetat, lactat, benzoat, and prussiat; from the solutions of these, sulphuric acid or sulphat of soda occasions a white heavy insoluble precipitate.

6. All salts whose base is strontian are nearly insoluble in water, as far as they have been examined, except six; namely, nitrat, muriat, hyperoxymuriat, acetat, tartrat, and citrat. These also yield an insoluble white powder with sulphuric acid. But the alkalies occasion no precipitate either in the solutions of barytic or strontian salts.

7. All salts whose base is lime are very sparingly soluble in water except nine; namely, nitrat, muriat, hyperoxymuriat, arseniat, acetat, malat, lactat, benzoat, and prussiat. The lime is precipitated from these solutions by oxalic acid, fixed alkalies, and by sulphuric acid if the solution be concentrated, but not by ammonia.

8. The magnesian salts are all soluble in water except seven; namely, phosphite, fluat, carbonat, oxalat, tartrat, saccolat, and camphorat. Their solution yields a white precipitate with ammonia, which disappears by adding ammonia in excess, provided there be an excess of acid present. This precipitate forms with sulphuric acid a very soluble bitter salt.

9. The alkaline earths form with acids a greater num-

* Four of them are still unknown; namely, the molybdat, chromat, gallat, and sebat.

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ber of salts soluble in water in proportion as the alkaline properties of the earth diminish. Barytes forms salts, the greater number of which are insoluble; strontian seems to form a greater number of soluble salts than barytes; lime forms a still greater number; and almost the whole of the magnesian salts are soluble in water.

10. Six of the aluminous salts are insoluble in water; namely, sulphite, phosphat, borat, arseniat, tungstat, and saccolat. The aluminous salts are all deprived of their acid by heat. With potass they yield a precipitate which dissolves in sulphuric acid; and when sulphat of potass is added to the solution, crystals of alum are gradually obtained. The aluminous salts let fall a precipitate when hydrosulphuret of potass is dropt into their solution, and at the same time sulphureted hydrogen gas is exhaled.

11. The salts of yttria are decomposed by heat and by alkalies; they have a sweetish astringent taste; triple prussiat of potass and infusion of nutgalls occasion a precipitate when poured into their solutions. The succinat of potass occasions no precipitate.

12. The salts of glucina are decomposed by heat and by alkalies; they have a sweetish taste. The precipitate separated from them by alkalies, redissolved in nitric or muriatic acid, is again precipitated by the infusion of nutgalls, but not by triple prussiat of potass. It is precipitated also by succinat of potass.

13. The zirconian salts have an austere taste: they are decomposed by heat and by alkalies. The precipitate separated from them by these last bodies, when redissolved in muriatic acid, is precipitated by hydrosul-

phuret of potass, triple prussiat of potass, and by the infusion of nutgalls.

Second Class,

The second class of salts, the metalline, may be distinguished by the following properties: The salts belonging to it are either, 1. Soluble in water; in which case they afford a precipitate with hydrosulphuret of potass, triple prussiat of potass *, and the infusion of nutgalls †: or, 2. Insoluble in water; in which case, when fused with borax by the blow-pipe upon charcoal, they either afford a button of metal, or form with the borax a coloured glass.

Divided into two orders.

This class might with propriety enough be divided into two orders. The first order would comprehend those genera, the salts belonging to which are crystallizable and permanent, indicating a marked affinity between the acid and base; the second order would consist of those salts which want permanency, and indicate a very weak affinity between the acid and base. The first order would consist of 13 genera; namely,

1. Salts of gold	8. Salts of nickel
2. . . . platinum	9. . . . . zinc
3. . . . silver	10. . . . . cobalt
4. . . . mercury	11. . . . . manganese
5. . . . copper	12. . . . . uranium
6. . . . iron	13. . . . . titanium
7. . . . lead	

The second order would consist of 9 genera; namely,

* Except salts of gold, platinum, antimony, and tellurium.

† Except salts of platinum, zinc, arsenic, and manganese.

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1. Salts of tin
2. . . . . bismuth
3. . . . . antimony
4. . . . . tellurium
5. . . . . arsenic
6. Salts of tungsten
7. . . . . molybdenum
8. . . . . chromium
9. . . . . columbium

The genera may be recognised without much difficulty by the characters given in the second Section of this Chapter. As the species are very numerous, it greatly facilitates investigation to subdivide them into sets. This accordingly has been done in the description of the genera, whenever the state of our knowledge rendered it practicable. These subdivisions are the five following: 1. Detonating salts. These detonate when heated with a combustible, and generally also when wrapt in a paper with a little phosphorus and struck smartly with a hammer. The acids in these salts are the nitric and hyperoxymuriatic. 2. Incombustible salts. These often lose their acid or a part of it when heated; but they do not burn, nor are they capable of setting fire to combustibles. The acids in these salts are the muriatic, sulphuric, sulphurous, phosphoric, phosphorous, carbonic, fluoric, boracic. The phosphats and borats are not decomposed by heat; but melt readily into a glass. Those sulphats that are soluble in water lose a great portion of their acid in a strong heat; but the insoluble sulphats scarcely lose any, unless the base be volatile. The muriats are readily volatilized when strongly heated. The sulphites and phosphites are converted by heat partly to sulphats and phosphats, and partly to sulphurets and phosphurets. The carbonats are decomposed by heat. The fluats undergo a partial decomposition, and usually melt into a glass. 3. Combustible salts. These contain the 15 combusti-

ble acids. When heated, they are decomposed; the base, usually contaminated with charcoal, and partially reduced to the metallic state, remains behind. Most of these salts are but imperfectly known. 4. Metallic salts. These contain both a metallic base and acid. They are all insoluble in water and alcohol, and seldom or never completely decomposed by heat. They often exist native. The analysis of them is usually difficult. 5. Triple salts. They contain, besides a metallic base, an alkali or earth. They are very numerous, though but imperfectly examined. In general, it may be laid down as a rule, that all metallic oxides soluble in alkalies are capable of forming triple salts with these alkalies and acids. The metallic triple salts claim peculiar attention on another account. Alkalies or earths are seldom capable of throwing down their metallic base. Unless, then, we be acquainted with all the triple salts that are liable to be formed, we must be very apt to fall into mistakes when these salts happen to occur in the course of our analysis.

The species in the different metallic genera may be distinguished from each other by the properties of the different acids which form them; and these properties have been enumerated in the first Section as the characteristic marks of the genera of earthy and metallic salts.

The following TABLE, which gives a synoptical view of the properties of the most important salts, will add considerably to the facility of distinguishing the different species.

Salts.	Taste.	Figure of Crystals.	Action of Air.	Solubility in 100 Parts Water at 60°.	Solubility in 100 Parts Water at 212°.	Action of Heat.
Sulphat of barytes -	None	Rhomboidal prisms	None	0.002	0.	Decrepitates
potass -	Bitter	Six-sided prisms	None	6.25	20.	Decrepitates
soda -	Bitter	Six-sided prisms	Effloresces	37.	125.	Watery fusion
strontian -	None	Rhomboidal prisms	None	0.00	0.02	
lime -	Little	Rhomboidal prisms	None	0.2	0.22	Decrepitates
ammonia -	Bitter	Six-sided prisms	Subdeliquesces	50.	100.	Decrepitates and melts
magnesia -	Bitter	Four-sided prisms	Effloresces	100.	133.	Watery fusion
Alum - - -	Astringent	Octahedrons	Little	5.	133.	Watery fusion
Sulphite of barytes -	None	Tetrahedrons	Chang. to Sulph	0.	0.	
lime -	None	Six-sided prisms	Effloresces	0.125		Falls to powder
potass -	Sulphur.	Rhomboidal plates	Effloresces	100.		Decrepitates
soda -	Sulphur.	Four-sided prisms	Effloresces	25.	100.	Watery fusion
ammonia -	Sulphur.	Six-sided prisms	Subdeliquesces	100.		Decrepitates
magnesia -	Little	Tetrahedrons	Effloresces	5.		Swells
Nitrat of barytes -	Acrid	Octahedrons	None	8.	25.	Decrepitates
potass -	Cooling	Six-sided prisms	None	14.25	100.	Melts
soda -	Cooling	Rhomboidal prisms	Subdeliquesces	33.	100. +	Melts
strontian -	Pungent	Octahedrons	Little	100.	200.	Decrepitates and melts
lime -	Bitter	Six-sided prisms	Deliquesces	400.	Any quantity	Watery fusion
ammonia -	Acrid	Six-sided prisms	Deliquesces	50.	200.	Melts
magnesia -	Bitter	Rhomboidal prisms	Deliquesces	100.	100. +	Watery fusion
Muriat of barytes -	Astringent	Four-sided prisms	None	20.		Decrepitates
potass -	Bitter	Cubes	None	33.		Decrepitates
soda -	Salt	Cubes	None	35.42	36.16	Decrepitates
strontian -	Sharp	Six-sided prisms	Little	150.	Any quantity	Watery fusion
lime -	Bitter	Six-sided prisms	Deliquesces	200.		Watery fusion
ammonia -	Acrid	Four-sided pyramids	Subdeliquesces	33.		Sublimes
magnesia -	Bitter	Needles	Deliquesces	100.		Watery fusion

Salts.	Taste.	Figure of Crystals.	Action of Air.	Solubility in 100 Parts Water at 60°.	Solubility in 100 Parts Water at 212°.	Action of Heat.
Oxymuriat of potass -	Cooling	Rhomboidal plates	None	6.	40.	Gives out oxygen
Phosphat of barytes -	None	o	None	o.	o.	Little
strontian -	None	o	None	o.	o.	Little
lime -	None	Six-sided prisms	None	o.	o.	Little
potass -	Salt	A gelatinous mass	Deliquesces	Very soluble		Watery fusion
soda -	Salt	Rhomboidal prisms	Effloresces	25.	50.	Watery fusion
ammonia -	Cooling	Four-sided prisms	None	25.	25. +	Watery fusion
magnesia -	Cooling	Six-sided prisms	Effloresces	6.6		Falls to a powder
Fluat of lime - -	None	Cubes	None	o.	c.	Decrepitates
Borax - -	Styptic	Six-sided prisms	Subefflorescs	8.4	168	Watery fusion
Carbonat of barytes -	None	Various	None	0.023	0.043	Little
strontian -	None		None	o.	0.065	Little
lime -	None	Rhomboidal prisms	None	o.	o.	Decrepitates
potass -	Alkaline	Four-sided prisms	None	25.	83⅓	Watery fusion
soda -	Alkaline	Octahedr. truncated	Effloresces	50.	100. +	Watery fusion
magnesia -	None	Six-sided prisms	Efflores es	2.		Decrepitates
ammonia -	Urinous	Irregular	None	50. +	100.	Evaporates
Acetite of barytes -	Bitter	Needles	Subefflorescs			Decomposed
potass -	Hot	Plates	Deliquesces	100.		Melts
soda -	Sharp	Striated prisms	None	35.		Melts
strontian -			None		40.8	Decomposed
lime -	Bitter		None			Decomposed
ammonia -	Cool	Slender prisms	Deliquesces	Very soluble		Melts and sublimes
magnesia -	Sweetish	o	Deliquesces	Very soluble		Decomposed
Tartar - - -	Acid	Irregular prisms	None	1⅔	3⅓	Melts
Tartrat of potass -	Bitter	Four-sided prisms	None	25.		Melts
Tartrat of potass-and-soda	Bitter	Eight-sided prisms	Effloresces	25.		Melts

CHAP. IV.

OF HYDROSULPHURETS.

Properties of sulphureted hydrogen.

SULPHURETED HYDROGEN GAS possesses the properties of an acid. It is absorbed by water in considerable quantities, and the solution reddens vegetable blues; it combines also with alkalies and earths, and with several metallic oxides. The greater number of these properties were first pointed out with precision by Mr Kirwan; but they were afterwards much more fully developed by Berthollet.

Liquid sulphureted hydrogen, or sulphureted hydrogen gas dissolved in water, is not decomposed by exposure to the air; but the gas is gradually separated and carried off by the air without decomposition. When sulphurous acid is mixed with this solution, both the sulphureted hydrogen and the acid are in a great measure decomposed; the hydrogen of the one combines with the oxygen of the other, and forms water; while the sulphur of both is precipitated, as was first observed by Fourcroy, and more fully ascertained by Berthollet. Nitric acid produces the same effect unless it be too much diluted with water. Hence the reason that sulphur precipitates when that acid is mixed with wa-

ter, holding sulphureted hydrogen in solution, as Bergman first observed. Oxymuriatic acid, on the other hand, converts the sulphureted hydrogen into water and sulphuric acid, by supplying both of its component parts with oxygen. Chap. IV.

Sulphureted hydrogen has a strong action on the greater number of metallic oxides; its hydrogen abstracts oxygen from these bodies, and thus either brings them to the metallic state or to a minimum of oxygen; while at the same time its sulphur combines with the metal thus regenerated. Hence the reason of the change produced upon the solutions of the metallic salts by the infusion of liquid sulphureted hydrogen. All the genera of metallic salts are precipitated by this substance excepting five; namely, those which contain the following metals: Precipitates metals.

1. Iron;
2. Nickel;
3. Cobalt;
4. Manganese;
5. Titanium; and also,
6. Molybdenum *.

Berthollet and Proust have shewn, that the oxides of these metals are reduced by sulphureted hydrogen to a minimum of oxygen; but as in that state they have but little affinity for sulphur, they continue combined with the acids which held them at first in solution. Tin, on the other hand, which at a minimum of oxidizement has a strong affinity for sulphur, is precipitated, though sulphureted hydrogen only reduces it to a minimum of oxidizement. Nature of the precipitates.

The metallic solutions differ considerably in the fa-

* When in the state of an acid and combined with an alkali.

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cility with which they afford precipitates with sulphureted hydrogen; and Mr Proust has shewn that, with a little address, metals may, in many cases, be separated from each other by means of this agent. For instance, if copper, lead, zinc, and iron, be held in solution together in nitric acid, sulphureted hydrogen first separates the copper in the form of a black precipitate, which may be removed by filtration; next, the lead; and, lastly, the zinc; while the iron still continues in solution *. The different metals may be distinguished by the colour of the precipitate which their solutions yield with sulphureted hydrogen. The colours of these different precipitates may be seen in the following TABLE:

Gold	Yellow
Silver	Black
Mercury	Black
Copper	Black
Tin	Brown
Lead	Black
Zinc	Yellow
Bismuth	Black
Antimony	Orange
Arsenic	Yellow
Molybdenum	Brown

Supersulphureted hydrogen.

Sulphureted hydrogen has the property of combining with sulphur, and of forming a compound which has the appearance of a yellow oil. It was first observed by Scheele †; and Berthollet ‡, who first examined its

* *Jour. de Phys.* li. 174.

† Scheele on *Fire*, p. 192. Eng. Transl.

‡ *Ann. de Chim.* xxv. 247.

nature, has given it the name of *hydrogenated sulphur*. When the compound of this last body and potass is poured by little and little into muriatic acid, scarcely any sulphureted hydrogen gas is exhaled, but hydrogenated sulphur gradually precipitates to the bottom of the vessel. This substance, when heated, easily allows the sulphureted hydrogen gas to exhale, and is converted into sulphur. The same change takes place when it is exposed to the open air.

Thus we see that sulphur and hydrogen are capable of combining in two proportions, or, which is the same thing, that hydrogen combines with two doses of sulphur. The first of these constitutes sulphureted hydrogen gas, or hepatic air; which, according to Thenard, is composed of about 29 hydrogen
71 sulphur

100

The addition of another dose of sulphur constitutes *hydrogureted sulphur*, which Mr Kirwan has with great propriety denominated *supersulphureted hydrogen;* a name which certainly ought to be adopted *. Both of these substances combine with different bases, and constitute very peculiar genera of compounds, which deserve a particular examination on account of the important purposes which they serve in analysis. The combinations which sulphureted hydrogen forms with bases have been called by Berthollet *hydrosulphurets*, and by Chenevix *sulphureted hydrogurets*. The compounds of supersulphureted hydrogen with bases have been called

* Kirwan on *Mineral Waters*, p. 11.

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by Berthollet *hydrogenated sulphurets*, and by Chenevix *hydrogureted sulphurets*†. Mr Chenevix's terms are certainly more precise than those of Berthollet; but as the word *hydrosulphuret* has been long in general use, it will be necessary to retain it. *Hydrogureted sulphuret*, however, may still be adopted; as the compounds denoted by it have been but seldom mentioned by chemists since the original paper by Berthollet on the subject.

I. Hydrosulphurets.

Sulphureted hydrogen combines with alkalies and earths, and forms with them compounds which may be distinguished by the following properties:

Properties.

1. They are all soluble in water, and the solution is colourless.

2. When the solution is exposed to the air, it becomes green or greenish yellow, and deposites sulphur on the sides of the vessel in the state of a fine black crust.

3. After long exposure to the air, the solution becomes limpid and colourless; and on examination is found to contain only the sulphat of the base of the original hydrosulphuret.

4. The solution of the hydrosulphurets precipitate all metallic solutions; iron and lead, black; antimony, orange; arsenic, yellow.

† On the *Chemical Nomenclature*, p. 201. Mr Kirwan uses the term *hepatule* instead of *hydrosulphuret*, and *hepar* for *hydrogureted sulphuret*.

Chap. IV.

How formed.

The hydrosulphurets may be formed by dissolving or mixing the bases respectively with water, and causing sulphureted hydrogen gas to pass through them till they refuse to absorb any more. The excess of the gas is driven off by heating the solution. It is proper to cause the sulphureted hydrogen gas to pass through a small vessel of water before it reaches the base with which it is to combine, in order to separate any impuritics with which it might be mixed. By this method solutions of the different hydrosulphurets in water may be obtained.

If these compounds be decomposed while they are colourless, by pouring upon them sulphuric acid, muriatic acid, or any other acid which does not act upon hydrogen, the sulphureted hydrogen gas exhales without the deposition of a single particle of sulphur; but if the hydrosulphuret has become yellow, some sulphur is always deposited during its decomposition, and the quantity of sulphur is proportioned to the deepness of the colour.

The yellow colour, therefore, which hydrosulphurets acquire by exposure to the atmosphere is owing to a commencement of decomposition. Part of the hydrogen of the sulphureted hydrogen abandons the sulphur, combines with the oxygen of the atmosphere, and forms water. By degrees, however, a portion of the sulphur is also converted into an acid; and when the proportion of sulphureted hydrogen is diminished, and that of the sulphur increased to a certain point, the sulphur and the hydrogen combine equally with oxygen.

If sulphuric or muriatic acids be poured upon a hydrosulphuret after it has been for some time exposed to

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the air, a quantity of sulphureted hydrogen gas exhales, sulphur is deposited, and after an interval of time sulphurous acid is disengaged. It is therefore sulphurous, and not sulphuric acid, which is formed while the hydrosulphuret spontaneously absorbs oxygen. This acid, however, is not perceptible till after a certain interval of time, when separated from the hydrosulphuret by means of an acid; because as long as it meets with sulphureted hydrogen a reciprocal decomposition takes place. The oxygen of the acid combines with the hydrogen of the gas, and the sulphur of both is precipitated.

The affinities of the alkalies and earths for sulphureted hydrogen appear from the experiments of Berthollet to be as follows:

Affinities.

Barytes,
Potass,
Soda,
Lime,
Ammonia,
Magnesia,
Zirconia.

Sp. 1. *Hydrosulphuret of Barytes.*

When sulphat of barytes is converted into sulphuret, by mixing it with charcoal and keeping it red hot in a crucible, if boiling water be poured upon the black mass, and filtered while hot; the green coloured solution thus obtained yields by evaporation a great number of crystals. These crystals are hydrosulphuret of barytes. They are to be separated immediately by filtration,

and dried between the folds of filtering paper *. They are white, and have a silky lustre. They have usually the form of scales, whose shape cannot be easily ascertained. This compound is soluble in water, and the solution has a very slight tinge of green. Its taste is acrid and sulphureous; and when exposed to the air it is readily decomposed.

Sp. 2. *Hydrosulphuret of Strontian.*

I have procured this compound by the same process as the hydrosulphuret of barytes, and its properties are so nearly similar, that it requires no peculiar description.

Sp. 3. *Hydrosulphuret of Potass.*

This compound may be procured by saturating potass with sulphureted hydrogen; but it is formed also during the solution of sulphuret of potass, and may be obtained by evaporation. Its properties have been lately described by Mr Vauquelin. It is transparent and colourless, and crystallizes in large prismatic crystals, not unlike sulphat of soda. They are usually four-sided, and terminated by four-sided pyramids. Sometimes both the prisms and terminating pyramids are six-sided. Its taste is alkaline, and extremely bitter. When exposed to the air it soon deliquesces into a liquid of a syrupy consistence, tinging green all bodies with which it happens to be in contact. But this colour is not permanent, unless some metallic body happens to be in contact. The crystals have no smell; but when they have deliquesced, they e-

* Berthollet, *Ann. de Chim.* xxv. 241.

mit a fetid odour. They dissolve both in water and alcohol; and during the solution the temperature of the liquid sinks considerably. Acids drive off the sulphureted hydrogen with a violent effervescence, and no sulphur is deposited. When thrown into sulphat of alumina, crystals of alum are soon deposited. This salt, like the other hydrosulphurets, precipitates all metals from their solutions *.

Sp. 4. *Hydrosulphuret of Soda.*

This compound may be prepared by the same processes as the last. It is the best known of all the hydrosulphurets, as it is usually employed as a reactive. The properties of its solution in water were first pointed out by Berthollet, but Vauquelin first obtained it crystallized. Having laid aside a concentrated solution of impure carbonat of soda † to crystallize, crystals of hydrosulphuret of soda formed in it spontaneously. The crystals of this hydrosulphuret are transparent and colourless, having the figure of four-sided prisms terminated by quadrangular pyramids, and sometimes of octahedrons. Its taste is alkaline and intensely bitter. It is very soluble both in water and alcohol; and during the solution cold is produced. When exposed to the air it deliquesces, and assumes a green colour. Acids decompose it, driving off the sulphureted hydrogen. Its other properties are common to the hydrosulphurets ‡.

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* Vauquelin, *Ann. de Chim.* xlii. 40.

† This carbonat had been procured by decomposing sulphat of soda by charcoal, and separating the sulphur by means of lime.

‡ Vauquelin, *Ann. de Chim.* xli. 190.

Sp. 5. Hydrosulphuret of Lime.

This compound is easily prepared by passing sulphureted hydrogen gas through lime suspended in water. The lime dissolves and the hydrosulphuret forms. The solution is colourless, and has an acrid and bitter taste. Its properties are analogous to the other hydrosulphurets. No attempts have been yet made to procure this compound in crystals.

Sp. 6. Hydrosulphuret of Ammonia.

This compound is easily procured by passing a current of sulphureted hydrogen through liquid ammonia. The solution very readily assumes a greenish yellow colour. When equal parts of lime, sal ammoniac, and sulphur, are distilled in a retort, a yellow liquid is obtained, usually distinguished by the name of *fuming liquor of Boyle*, because first prepared by that philosopher. This liquid constantly emits white fumes, and has a strong ammoniacal and fetid odour. Berthollet ascertained that it owed its property of emitting fumes to a quantity of uncombined alkali. It consists chiefly of hydrosulphuret of ammonia, holding an excess of sulphur. This liquid gradually loses the property of fuming, and deposites likewise its excess of sulphur. It is then a hydrosulphuret of ammonia nearly pure.

Sp. 7. Hydrosulphuret of Magnesia.

Water, impregnated with sulphureted hydrogen, dissolves magnesia, and forms a hydrosulphuret, the properties of which have not been examined *.

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* Berthollet, *Ann. de Chim.* xxv. 235.

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Sp. 8. *and* 9. *Hydrosulphuret of Glucina and Yttria.*

From the experiments of Vauquelin and Klaproth, we know that the hydrosulphurets do not precipitate those earths from acids. Hence it is likely that they are capable of combining with sulphureted hydrogen; though the compounds have never been examined by chemists. Neither alumina nor zirconia combine with sulphureted hydrogen. Hence the hydrosulphurets precipitate these earths from acids, in consequence of the affinity of their base for the acid, which holds the earths in solution; and at the same time sulphureted hydrogen gas is emitted.

II. Hydrogureted Sulphurets.

The different alkaline and earthy bases are capable of combining with supersulphureted hydrogen, and forming with it compounds which have been longer known than the hydrosulphurets, though their properties have not been examined with the same precision. They may be formed by boiling the base together with sulphur in a quantity of pure water, or by dissolving their sulphurets in water; in either case, supersulphureted hydrogen is formed, which combines with the base. These compounds were known formerly by the name of *liquid hepars*, or *livers of sulphur*. They may be formed also, as Berthollet has shown, by pouring a liquid hydrosulphuret upon sulphur. A portion of the sulphur is dissolved without the assistance of heat; the liquid becomes dark-coloured, and is converted into hy-

How formed.

drogenated sulphuret*. When prepared by the first process, they contain an excess of sulphur, which separates when sulphureted hydrogen is made to pass through them. These liquids have been noticed already while treating of the different bases.

1. Hydrogureted sulphuret of potass or soda may be prepared by boiling together a mixture of the pure alkalies and sulphur in water: For though the alkalies scarcely attack sulphur while cold, they readily dissolve it while hot. This solution is of a deep greenish-yellow colour, has an acrid and intensely bitter taste, and acts with great energy upon most bodies. When exposed to the air it rapidly absorbs oxygen. When kept in close vessels, it gradually deposites sulphur, and becomes much more transparent and lighter coloured, at the same time the smell perceptibly diminishes. It attacks with great energy every metal, and often reduces it to the state of a sulphuret. Stahl demonstrated long ago, that it is capable of dissolving even gold. The nature of his solution has not been ascertained. By means of acids the gold is thrown down in the metallic state, and mixed with sulphur.

2. Ammonia has no action on sulphur, even when assisted by heat: but the hydrogureted sulphuret of ammonia may be obtained by pouring on sulphur the hydrosulphuret of ammonia. The last portions of the liquid which passes over during the distillation of the *fuming liquor of Boyle* is also a hydrogureted sulphuret. This compound very readily deposites the excess of sulphur which

* *Ann. de Chim.* xxv. 242.

it contains, and approaches to the state of a hydrosulphuret.

3. The hydrogureted sulphurets of barytes and strontian may be procured by dissolving their sulphurets in water, or even by exposing them to the open air. They have a green colour and acrid taste, but much inferior in intensity to the fixed alkaline hydrogureted sulphurets; neither is their action on other bodies so powerful.

4. When a mixture of lime and sulphur is boiled in water, the liquid assumes a beautiful orange colour, and contains in solution hydrogureted sulphuret of lime. This liquid has likewise a very bitter taste. It is the only liquid at present known which is capable of dissolving a notable quantity of azotic gas. When kept in close phials, it gradually deposites sulphur in the state of black crust, and becomes perfectly colourless.

5. The hydrogureted sulphuret of ammonia may be formed by the same processes as the others. This compound has scarcely been examined. It has but little permanency.

6. It has not been proved that the earths proper are capable of combining with supersulphureted hydrogen, and forming hydrogureted sulphurets.

III. Metallic hydrosulphurets and hydrogureted sulphurets.

The hydrosulphurets and hydrogureted sulphurets have the property of precipitating all metallic bodies from any solution in which they may be contained. They are therefore very valuable tests of the presence of metals, as they do not precipitate any of the earths ex-

cept alumina and zirconia. The metallic precipitates are occasioned by the combination of sulphureted hydrogen, supersulphureted hydrogen, or of sulphur with the metallic body, which is always deprived of a portion or of the whole of its oxygen, while at the same time the base of the hydrosulphuret combines with the acid which held the oxide in solution. The precipitate of alumina and zirconia is occasioned by the base of the hydrosulphuret, while the sulphureted hydrogen is exhaled in the state of gas, not being susceptible of combining with these earths. Hydrosulphuret, or hydrogureted sulphuret of potass or ammonia, is usually made choice of for these precipitations; and the peculiar metal precipitated may in many cases be ascertained by the colour of the precipitate. The colour of these different precipitates may be seen by the following TABLE:

Metals	Precipitate by Hydrosulphuret of Potass	Precipitate by Hydrogureted sulphuret of Potass.
Gold	Yellow	Yellow.
Silver	Black	Black.
Mercury	Brown black	Brown, becoming black.
Copper	Black	Brown.
Iron	Black	Black, becoming yellow.
Tin	Black	Black.
Lead	Black	White, becoming black.
Nickel	Black	Black.
Zinc	White	White.
Bismuth	Black	Black.
Antimony	Orange	Orange-yellow.
Tellurium	Black?	Deep brown or black.
Arsenic	Yellow	Yellow.

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Metals	Precipitate by Hydrosulphuret of Potass	Hydrogureted sulphuret of Potass.
Cobalt	Black	Black.
Manganese	White	White.
Uranium	Brown	Brownish-yellow *.
Titanium	Glass-green	Bluish-green *.
Chromium	Green	

The nature of these precipitates has been very much overlooked by chemists; yet the subject deserves a very particular investigation, as it would enable us to ascertain the nature of the compounds which metals and their oxides form with sulphur and its compounds with hydrogen. The following remarks are all that can be at present offered.

1. All metals (except perhaps gold and titanium), combine with sulphur, and form sulphurets which are tasteless, insoluble in water, and brittle.

The following Table exhibits a view of the colour of these compounds, and of the quantity of sulphur contained in each, as far as it has been ascertained:

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* In these experiments hydrosulphuret of ammonia was used by Klaproth.

Sulphuret of	Colour.	Sulphur.
Platinum	Black ?	
Silver	Black	0.13
Mercury	Red	0.15
Copper	Black blue	0.22
Iron	Black	0.60
Tin	Blue black	0.20
Lead	Blue	0.132
Nickel	Yellow ?	
Zinc	Brown	0.18 ?
Bismuth	Blue	0.15
Antimony	Blue	0.25
Tellurium	Blue	
Arsenic	Red Yellow	0.20
Cobalt	Yellow	
Manganese		
Tungsten	Bluish black	
Molybdenum	Blue	0.40
Uranium	Black	
Chromium		
Columbium		
Tantalium		

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All the sulphurets which have a blue colour, have at the same time less or more of the metallic lustre. When reduced to powder they often lose that lustre, and then always become black.

2. Two metallic sulphurets are capable of combining with an additional dose of sulphur, and becoming supersulphurets. These are copper and iron.

Supersulphuret of	Colour.	Sulphur.
Copper	Yellow	
Iron	Yellow	0.68

3. Two metallic oxides are capable of combining with sulphur, and forming compounds called sulphureted oxides. These are tin and manganese.

Sulphureted oxide of	Colour.	Sulphur.
Tin	Yellow	0.60
Manganese	Green	

4. Whether metals be capable of combining with supersulphureted hydrogen has not been properly ascertained. Certain metallic compounds contain it; but whether the metal in these cases be oxidized or not, is unknown. Proust, whose sagacity and consummate skill in this branch of chemistry entitle his opinion to great respect, inclines to the last opinion with respect to some of these compounds. It is probable that all the compounds of metallic bodies and sulphur which exhale sulphureted hydrogen, when treated with mu-

riatic acid, and are only partially soluble, are in the state of hydrogureted sulphurets. Now this is the case with the following compounds:

1. Black sulphuret of mercury, or ethiops mineral*.
2. Black sulphuret of copper precipitated by hydrosulphuret of potass.
3. Black sulphuret of iron by ditto.
4. Black sulphuret of lead by ditto.
5. Black sulphuret of nickel by ditto.
6. Black sulphuret of bismuth? by ditto.
7. Black sulphuret of cobalt by ditto.
8. Yellow sulphuret of uranium? by ditto.
9. Green sulphuret of titanium? by ditto.
10. Some varieties of native sulphuret of antimony †.

All these compounds are most probably hydrogureted sulphurets; and in all of them, if we except the first and last, I have no doubt that the metals are in the state of protoxides.

5. Several of the metallic oxides are capable of combining with sulphureted hydrogen, and forming hydrosulphurets. The metals which enter into these combinations seem to be always in the state of protoxides; at least that is the case with all those hitherto examined. Whether all metallic protoxides are capable of combining with sulphureted hydrogen is unknown; but it is not likely. The following are the metallic hydrosulphurets which are at present known.

Hydrosulphuret of Zinc.—Zinc is thrown down from acids in the state of a white mass by the hydrosulphuret of potass or ammonia. This mass dissolves com-

* Berthollet, *Ann. de Chim.* xxv. 262. † Bergman.

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pletely in muriatic acid, and at the same time a great quantity of sulphureted hydrogen is exhaled. Hence it is obviously a hydrosulphuret. It may be formed also by treating the white oxide of zinc with hydrosulphuret of ammonia*. Vauquelin remarks that the transparent specimens of *native sulphuret of zinc* or Blende. *blende* often dissolve in the same way, emitting sulphureted hydrogen †. It is very probable that these specimens approach the nature of hydrosulphuret of zinc. In that case there would be three different kinds of minerals at present confounded under the term *blende*; namely, sulphuret of zinc, sulphureted oxide of zinc, and hydrosulphuret of zinc. But this must be left for subsequent investigation.

Hydrosulphuret of Antimony.—When hydrosulphuret of potass or ammonia is dropt into an acid solution of antimony, a beautiful orange-coloured precipitate falls, which the experiments of Berthollet, Thenard, and Proust have demonstrated to be a hydrosulphuret Kermes mineral. of antimony. This compound, under the name of *kermes mineral*, acquired very great celebrity for its medical virtues about the beginning of the 18th century. The method of preparing it was first discovered by Glauber, and afterwards by Lemery the Elder; but it was first brought into vogue in France by a priest called Simon, who was taught the secret of preparing it by La Ligerie, a surgeon, to whom it had been communicated by a pupil of Glauber. The French government purchased the secret from La Ligerie, and published the pre-

* See Berthollet's Table, *Ann. de Chim.* xxv. 272.

† *Ann. de Chim.* xxxvii. 66.

cess in 1720. It was very tedious and ill contrived, consisting in boiling repeatedly a very diluted solution of potass on sulphuret of antimony; a small portion of kermes precipitated as the solution cooled. The process of Lemery was therefore adopted by apothecaries. It is the following:

Sixteen parts of sulphuret of antimony, eight parts of potass of commerce, and one part of sulphur, are triturated together in a mortar, melted in a crucible, and the mass poured into an iron vessel. When cold it is pounded, and boiled in a sufficient quantity of water, and the solution is filtered while hot. On cooling, it deposites the kermes abundantly in the state of a yellow powder, which is edulcorated with a sufficient quantity of water, and dried: Or six parts of potass may be dissolved in twenty parts of water; and to this solution, previously made boiling hot, one part of pounded sulphuret of antimony may be added. The solution, well agitated, boiled for seven or eight minutes, and filtered while hot, deposites on cooling abundance of kermes.

This powder occupied a good deal of the attention of chemists. Bergman first demonstrated that it contained sulphureted hydrogen; but it was Berthollet who first pointed out its true composition. From the analysis of Thenard it follows that it is composed of

20.30 sulphureted hydrogen
4.15 sulphur
72.76 protoxide of antimony
2.79 water and loss

100.00*

* *Ann. de Chim.* xxxii. 268.

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When this substance is exposed to the air, it gradually absorbs oxygen and becomes white, and the sulphureted hydrogen exhales.

After the mineral kermes has precipitated from its solution, prepared by either of the formulas above described, if an acid be added to the liquid, another precipitate is produced of an orange colour, hence called *sulphur auratum*. According to the analysis of Thenard, it is composed of

Sulphur auratum.

17.87. sulphureted hydrogen
68.30 protoxide
12.00 sulphur

98.17 †

Hence it is a hydrosulphuret with excess of sulphur and a smaller proportion of base. Goettling has proposed the following process for obtaining this compound: Two parts of sulphuret of antimony and three parts of sulphur, well mixed, are dissolved in a boiling solution of pure potass; the solution is then diluted with water, and precipitated by means of weak sulphuric acid †.

Hydrosulphuret of Manganese.—When the black oxide of manganese is treated with sulphureted hydrogen water, its black colour disappears; a portion of the sulphureted hydrogen is decomposed at the expence of the oxygen of the black oxide; and the white oxide, thus evolved, is dissolved by the sulphureted hydrogen, and

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* *Ann. de Chim.* xxxii. 268.

† Bergman, iii. 172. The experiments of Proust on these compounds are highly interesting, but too long for insertion here. See *Jour. de Phys.* lv. 328.

by evaporation a white mass is obtained, which dissolves completely in muriatic acid, while abundance of sulphureted hydrogen is exhaled. It is therefore a hydrosulphuret of manganese *. The same compound is obtained when hydrosulphuret of potass is mixed with a salt of manganese.

Hydrosulphuret of Arsenic.—Sulphureted hydrogen combines with the white oxide of arsenic dissolved in water. The liquid assumes a yellow colour, but no precipitate appears. Hence the hydrosulphuret of arsenic, like that of manganese, is soluble in water, at least by the assistance of an excess of sulphureted hydrogen. This hydrosulphuret exactly resembles in appearance yellow sulphuret of arsenic.

Hydrosulphuret of Iron.—Sulphureted hydrogen combines with the green oxide of iron, and the compound is soluble in water; but the solution soon lets fall a black powder, which is a hydrogureted sulphuret of iron.

6. Thus we see that there are no less than five different compounds, consisting chiefly of metals or their oxides, combined with sulphur; namely,

1. Sulphurets.
2. Supersulphurets.
3. Sulphureted oxides.
4. Hydrogureted sulphurets.
5. Hydrosulphurets.

It is now easy to see the state in which the different metals are precipitated from acids by the hydrosulphurets. Silver, molybdenum, and perhaps also tin, are

* Berthollet, *Ann. de Chim.* xxv. 258.

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precipitated in the state of sulphurets. Mercury, copper, iron, lead, nickel, bismuth, and perhaps also cobalt, uranium, and titanium, are precipitated in the state of hydrogureted sulphurets; while zinc, antimony, arsenic, and manganese, are thrown down in the state of hydrosulphurets. But this important subject requires a much more complete investigation than it has hitherto received.

CHAP. V.

OF SOAPS.

The fixed oils have the property of combining with alkalies, earths, and metallic oxides, and of forming with these bodies a class of compounds which have received the name of Soaps. As these soaps differ from each other very materially, according as their base is an alkali, an earth, or an oxide, it will be proper to consider each set separately. This will be the subject of the three following Sections.

SECT. I.

OF ALKALINE SOAPS.

As there are a great number of fixed oils, all or most of which are capable of combining with alkalies, earths, and oxides, it is natural to suppose that there are as many genera of alkaline soaps as there are oils. That there are differences in the nature of soaps corresponding to the oil which enters into their composition, is certain; but these differences are not of sufficient im-

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portance to require a particular description. It will be sufficient therefore to divide the alkaline soaps into as many species as there are alkalies, and to consider those soaps which have the same alkaline base, but differ in their oil, as varieties of the same species.

Sp. 1. *Soap of Soda or Hard Soap.*

History.

THE word *soap* (*sapo*, σαπων) first occurs in the works of Pliny and Galen, and is evidently derived from the old German word *sepe* *. Pliny informs us that soap was first discovered by the Gauls; that it was composed of tallow and ashes; and that the German soap was reckoned the best †.

Preparation.

Soap may be prepared by the following process: A quantity of the soda of commerce is pounded and mixed in a wooden vessel, with about a fifth part of its weight of lime, which has been slacked and passed through a sieve immediately before. Upon this mixture a quantity of water is poured, considerably more than what is sufficient to cover it, and allowed to remain on it for several hours. The lime attracts the carbonic acid from the soda, and the water becomes strongly impregnated with the pure alkali. This water is then drawn off by means of a stop-cock, and called the *first ley*. Its specific gravity should be about 1.200.

Another quantity of water is then to be poured upon the soda, which, after standing two or three hours,

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* Beckmann's *History of Inventions*, iii. 239. A similar word is still used by the common people of Scotland.

† Pliny, lib. xviii. c. 51.

is also to be drawn off by means of the stop-cock, and called the *second ley*.

Another portion of water is poured on; and after standing a sufficient time, is drawn off like the other two, and called the *third ley*.

Another portion of water may still be poured on, in order to be certain that the whole of the soda is dissolved; and this weak ley may be put aside, and employed afterwards in forming the first ley in subsequent operations.

A quantity of oil, equal to six times the weight of the soda used, is then to be put into the boiler, together with a portion of the *third* or *weakest ley*; and the mixture must be kept boiling and agitated constantly by means of a wooden instrument. The whole of the third ley is to be added at intervals to the mixture; and after it is consumed, the *second ley* must be added in the same manner. The oil becomes milky, combines with the alkali, and after some hours it begins to acquire consistence. A little of the *first ley* is then to be added, not forgetting to agitate the mixture constantly. Portions of the first ley are to be added at intervals; the soapy substance acquires gradually greater consistency, and at last it begins to separate from the watery part of the mixture. A quantity of common salt is then to be added, which renders the separation much more complete. The boiling is to be continued still for two hours, and then the fire must be withdrawn, and the liquor must be no longer agitated. After some hours repose the soap separates completely from the watery part, and swims upon the surface of the liquor. The watery part is then to be drawn off; and as it contains

a quantity of carbonat of soda, it ought to be reserved for future use.

The fire is then to be kindled again; and, in order to facilitate the melting of the soap, a little water, or rather weak ley, is to be added to it. As soon as it boils, the remainder of the first ley is to be added to it at intervals. When the soap has been brought to the proper consistence, which is judged of by taking out small portions of it and allowing it to cool, it is to be withdrawn from the fire, and the watery part separated from it as before. It is then to be heated again, and a little water mixed with it, that it may form a proper paste. After this let it be poured into the vessels proper for cooling it; in the bottom of which there ought to be a little chalk in powder, to prevent the soap from adhering. In a few days the soap will have acquired sufficient consistence to be taken out, and formed into proper cakes *.

The use of the common salt in the above process is to separate the water from the soap; for common salt has a stronger affinity for water than soap has.

Olive oil has been found to answer best for making soap, and next to it perhaps tallow may be placed: but a great variety of other oils may be employed for that purpose, as appears from the experiments of the French chemists above quoted. They found, however, that linseed oil and whale oil were not proper for making *hard soaps*, though they might be employed with advantage in the manufacture of *soft soaps*. Whale oil has been long used by the Dutch for this last purpose.

* See the Memoir of Darcet, Lelievre, and Pelletier, in the *Ann. de Chim.* xix. 253.

Chap. V.

Soap may also be made without the assistance of heat; but in that case a much longer time and a larger proportion of alkali is necessary.

Sophistication.

Manufacturers have contrived various methods of sophisticating soap, or of adding ingredients which increase its weight without increasing its value. The most common substance used for that purpose is water; which may be added in considerable quantities, especially to soap made with tallow (the ingredient used in this country), without diminishing its consistency. This fraud may be easily detected, by allowing the soap to lie for some time exposed to the air. The water will evaporate from it, and its quantity will be discovered by the diminution of the weight of the soap. As soap sophisticated in this manner would lose its water by being kept, manufacturers, in order to prevent that, keep their soap in saturated solutions of common salt; which do not dissolve the soap, and at the same time, by preventing all evaporation, preserve, or rather increase the weight of the soap. Messrs Darcet, Lelievre, and Pelletier, took two pieces equal in weight of soap sophisticated in this manner, and placed the one in a dry place in the open air, and the other in a saturated solution of common salt. After a month the first had lost 0.56 of its weight, the other had gained about 0.10 parts *. Various other methods have been fallen upon to sophisticate soap; but as they are not generally known, it would be doing an injury to the public to describe them here.

Analysis.

Different chemists have analysed soap, in order to as-

* *Ann. de Chim.* xix. 330.

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certain the proportions of its ingredients; but the result of their experiments is various, because they used soap containing various quantities of water. From the experiments of Darcet, Lelievre, and Pelletier, it appears that soap newly made and exposed to sale contains

60.94 oil
8.56 alkali
30.50 water

100.00

Soap is soluble both in water and in alcohol. Its properties as a detergent are too well known to require any description.

Soap made with tallow and soda has a white colour, and is therefore known by the name of *white* soap: but it is usual for soap-makers, in order to lower the price of the article, to mix a considerable portion of rosin with the tallow; this mixture forms the common *yellow soap* of this country.

Sp. 2. *Soap of Potass or Soft Soap.*

Formation.

POTASS may be substituted for soda in making soap, and in that case precisely the same process is to be followed. It is remarkable, that when potass is used, the soap does not assume a solid form; its consistence is never greater than that of hog's lard. This is what in this country is called *soft soap*. Its properties as a detergent do not differ materially from those of *hard soap*, but it is not nearly so convenient for use. The alkali employed by the ancient Gauls and Germans in the formation of soap was potass; hence we see the reason that it is described by the Romans as an unguent

The oil employed for making soft soap in this country is whale oil. A little tallow is also added, which, by peculiar management, is dispersed through the soap in fine white spots.

Some persons have affirmed that they knew a method of making hard soap with potass. Their method is this: After forming the soap in the manner above described, they add to it a large quantity of common salt, boil it for some time, and the soap becomes solid when cooled in the usual way. That this method may be practised with success has been ascertained by Messrs Darcet, Lelievre, and Pelletier: but then the hard soap thus formed does not contain potass but soda; for when the common salt (muriat of soda) is added, the potass of the soap decomposes it, and combines with its muriatic acid, while at the same time the soda of the salt combines with the oil, and forms hard soap: and the muriat of potass formed by this double decomposition is dissolved in water, and drawn off along with it *.

Soap of wool.

Chaptal has lately proposed to substitute wool in place of oil in the making of soap. The ley is formed in the usual manner, and made boiling hot, and shreds of woollen cloth of any kind are gradually thrown into it; they are soon dissolved. New portions are to be added sparingly, and the mixture is to be constantly agitated. When no more cloth can be dissolved, the soap is made †. This soap is said to have been tried with success. It might doubtless be substituted for soap with advantage in several manufactures, provided it can be

* *Ann. de Chim.* xix. 322.

† Ibid. xxi. 27.

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obtained at a cheaper rate than the soaps at present employed.

Fish soap.

Some time ago a proposal was made to substitute the muscles of fish instead of tallow or oil in the manufacture of soap; but the experiments of Mr Jamieson have demonstrated that they do not answer the purpose *.

Sp. 3. *Soap of Ammonia.*

This soap was first particularly attended to by Mr Berthollet. It may be formed by pouring carbonat of ammonia on soap of lime. A double decomposition takes place, and the soap of ammonia swims upon the surface of the liquor in the form of an oil; or it may be formed with still greater ease by pouring a solution of muriat of ammonia into common soap dissolved in water.

It has a more pungent taste than common soap. Water dissolves a very small quantity of it; but it is easily dissolved in alcohol. When exposed to the air, it is gradually decomposed. The substance called *volatile liniment*, which is employed as an external application in rheumatisms, colds, &c. may be considered as scarcely any thing else than this soap.

All the alkaline soaps agree in the properties of solubility in water and alcohol, and in being powerful detergents.

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* Nicholson's *Journal*, iii. 113.

SECT. II.

OF EARTHY SOAPS.

THE earthy soaps differ essentially from the alkaline in their properties. They are insoluble in water, and incapable of being employed as detergents. They may be formed very readily by mixing common soap with a solution of an earthy salt: the alkali of the soap combines with the acid of the salt; while the earth and oil unite together and form an earthy soap. Hence the reason that all waters holding an earthy salt are unfit for washing. They decompose common soap, and form an earthy soap insoluble in water. These waters are well known by the name of *hard* waters. Hitherto the earthy soaps have been examined by Mr Berthollet only.

Sp. 1. *Soap of Lime.*

THIS soap may be formed by pouring lime-water into a solution of common soap. It is insoluble both in water and alcohol. Carbonat of fixed alkali decomposes it by compound affinity *. It melts with difficulty, and requires a strong heat.

Soap of barytes and of strontian resemble almost exactly the soap of lime.

* Thouvenel.

Sp. 2. *Soap of Magnesia.*

This soap may be formed by mixing together solutions of common soap and sulphat of magnesia. It is exceedingly white. It is unctuous, dries with difficulty, and preserves its whiteness after desiccation. It is insoluble in boiling water. Alcohol and fixed oil dissolve it in considerable quantity. Water renders its solution in alcohol milky. A moderate heat melts it; a transparent mass is formed, slightly yellow, and very brittle *.

Sp. 3. *Soap of Alumina.*

This soap may be formed by mixing together solutions of alum and of common soap. It is a flexible soft substance, which retains its suppleness and tenacity when dry. It is insoluble in alcohol, water, and oil. Heat easily melts it, and reduces it to a beautiful transparent yellowish mass †.

SECT. III.

OF METALLIC SOAPS AND PLASTERS.

Metallic oxides are capable of combining with oils by two different processes: 1. By mixing together a

* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.
† Ibid.

solution of common soap with a metallic salt. 2. By uniting the metallic oxide with the oil directly, either cold or by the assistance of heat. The first of these combinations is called a *metallic soap*; the second a *plaster*. Let us consider each of these in their order.

I. *Metallic Soaps.*

THESE soaps have been examined by Mr Berthollet; who has proposed some of them as paints, and others as varnishes; but it does not appear that any of them has been hitherto applied to these purposes.

1. *Soap of mercury* may be formed by mixing together a solution of common soap and of corrosive muriat of mercury. The liquor becomes milky, and the soap of mercury is gradually precipitated. This soap is viscid, not easily dried, loses its white colour when exposed to the air, and acquires a slate colour, which gradually becomes deeper, especially if exposed to the sun or to heat. It dissolves very well in oil, but sparingly in alcohol. It readily becomes soft and fluid when heated *.

2. *Soap of zinc* may be formed by mixing together a solution of sulphat of zinc and of soap. It is of a white colour, inclining to yellow. It dries speedily, and becomes friable †.

3. *Soap of cobalt*, made by mixing nitrat of cobalt and common soap, is of a dull leaden colour, and dries with difficulty, though its parts are not conducted.

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* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.

† Ibid.

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Mr Berthollet observed, that towards the end of the precipitation there fell down some green coagula, much more consistent than soap of cobalt. These he supposed to be a soap of nickel, which is generally mixed with cobalt *.

4. *Soap of tin* may be formed by mixing common soap with a solution of tin in nitro-muriatic acid. It is white. Heat does not fuse it like other metallic soaps, but decomposes it †.

5. *Soap of iron* may be formed by means of sulphat of iron. It is of a reddish-brown colour, tenacious, and easily fusible. When spread upon wood, it sinks in and dries. It is easily soluble in oil, especially of turpentine. Berthollet proposes it as a varnish ‡.

6. *Soap of copper* may be formed by means of sulphat of copper. It is of a green colour, has the feel of a resin, and becomes dry and brittle. Hot alcohol renders its colour deeper, but scarcely dissolves it. Ether dissolves it, liquefies it, and renders its colour deeper and more beautiful. It is very soluble in oils, and gives them a pleasant green colour §.

7. *Soap of lead* may be formed by means of acetite of lead. It is white, tenacious, and very adhesive when heated. When fused it is transparent, and becomes somewhat yellow if the heat be increased ||.

8. *Soap of silver* may be formed by means of nitrat of silver. It is at first white, but becomes reddish by exposure to the air. When fused, its surface becomes

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* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.
† Ibid. ‡ Ibid. § Ibid || Ibid

covered with a very brilliant iris; beneath the surface it is black *. Chap. V.

9. *Soap of gold* may be formed by means of muriat of gold. It is at first white, and of the consistence of cream. It gradually assumes a dirty purple colour, and adheres to the skin so that it is difficult to efface the impression †.

10. *Soap of manganese* may be formed by means of sulphat of manganese. It is at first white, but it assumes in the air a reddish colour, owing evidently to the absorption of oxygen. It speedily dries to a hard brittle substance, and by liquefaction assumes a brown blackish colour ‡.

II. *Plasters.*

Properties.

PLASTERS are combinations of oils and metallic oxides destined to be spread upon leather or cloth, and in that state to be applied as a covering of ulcers, &c. They ought to be solid bodies, not so hard as to refuse to spread easily and equally, nor so soft as to run into oil when heated by the skin. They ought to admit of being easily kneaded when heated with the hand, to adhere firmly to the skin, but to be capable of being removed without leaving behind them any stain. Without these properties they do not answer the purpose for which they are destined, which is chiefly adhesion.

The only chemist who has hitherto examined plasters with attention is Deyeux, to whom we are indebt-

* Berthollet, *Mem. Par.* 1780, or Nicholson's *Journal*, i. 170.
† Ibid. ‡ Ibid.

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ed for some excellent observations on the method of preparing them *.

Oxides used.

The oxides hitherto employed for making plasters are those of lead; and *litharge* is usually considered as the best adapted for that purpose of any of these oxides. But the oxides of several of the other metals, as bismuth and mercury, are also capable of forming plasters, and might perhaps in some cases be employed with advantage. Some metallic oxides, however, as those of iron, are not susceptible of that kind of combination with oils which constitutes plasters †.

Oils.

All the fixed oils are capable of forming plasters; but they do not all form plasters with the same properties. The *drying* oils, linseed oil for instance, form plasters of a much softer consistency than the *fat* oils; but these last acquire the same properties as the drying oils if they be combined with mucilage. Thus olive oil, boiled for some time with linseed or fenugrec, forms with litharge plasters as soft as those composed of linseed oil and litharge. According to Deyeux, olive oil answers better for plasters than any other.

Formation.

1st Process.

There are three different ways of forming plasters. The first consists in simply mixing together oil and litharge in proper proportions, and allowing the mixture to remain a considerable time in the common temperature of the atmosphere, agitating it occasionally. The oxide gradually loses its colour and combines with the oil, and the mixture acquires consistence. This process is tedious, and does not furnish plasters sufficiently

* *Ann. de Chim.* xxxiii. 50.

† Deyeux, Ibid.

solid to answer the purposes for which they are intended. It is not therefore employed. Chap. V.

The second method consists in throwing the oxide into the oil while boiling. Plasters formed by this process have always a deep colour and a peculiar odour, occasioned by the decomposition of a portion of the oil. When this process is followed, it is necessary that the oxide should be in the state of a fine powder; and that by agitation it should be made to combine with the oil as fast as possible, otherwise the metal will be revived altogether, in consequence of the strong tendency which oil has to combine with oxygen when raised to a high temperature. 2d Process.

The third method is most frequently practised, because it is not liable to the same inconveniences as the other two. This method consists in boiling the oil and the oxide together in a sufficient quantity of water. By this liquid the heat is moderated at first till the oil and oxide combine, which prevents the revival of the metal; and afterwards when the water is dissipated, the temperature is sufficiently high to give the plaster the requisite consistency. 3d Process.

Plasters, when long kept, become often too hard to be fit for use, especially if the requisite proportion of oil has not been employed at first. This defect is easily remedied, by melting them with a small portion of new oil. Plasters, when long kept, likewise change their colour, and most of their sensible properties: owing either to the absorption of oxygen, or to some change produced in their component parts by the action of the air.

CHAP. VI.

REMARKS ON THE SECONDARY COMPOUNDS.

THE secondary compounds are incomparably more numerous than the primary; because they approach much nearer the actual component parts of the mineral, vegetable, and animal kingdoms. Indeed a very considerable proportion of them exist native, especially in the mineral kingdom; and that number will no doubt increase as the science of chemistry extends its bounds.

Secondary compounds resemble simple bodies.

Few of the secondary compounds have that activity, that violent action, upon other bodies, which distinguish the primary compounds. In this respect they bear a strong resemblance to the simple substances. Sulphur, for instance, is a body which has scarcely any taste, and which acts but feebly upon animals, and not at all perceptibly upon vegetables and minerals; and oxygen, though it undoubtedly merits the appellation of an active body, shews neither in its taste nor in its action on animals and vegetables any thing which deserves the name of acrid or caustic; but sulphuric acid, though composed of these two inoffensive bodies, is one of the most active and corrosive substances known, and burns and decomposes almost all the animal and vegetable bodies which are exposed to its influence. Potass is, if possible, still more corrosive; even the hardest mine-

ral is unable to resist its action. But sulphat of potass, though composed of these two formidable bodies, is not more active than sulphur itself. This singular correspondence between simple substances and secondary compounds, and the striking contrast between them and the primary compounds, deserve attention. It demonstrates to us, that the activity of bodies is not proportional to their simplicity, as has been hitherto supposed; and that there is some other cause besides combination with other bodies to blunt their energy.

None of them gaseous

Several of the simple bodies exist commonly in the state of gas: this is the case also with the primary compounds; but no gaseous body is found among the secondary compounds, and only a comparatively small number of liquid bodies. Almost all of them are solid, and probably every one of them is susceptible of assuming that form. Hence we see that gaseous bodies have all of them a considerable degree of simplicity; none of them, as far as is known, containing more than two component parts, if we omit the consideration of caloric and light altogether; or three component parts, if we include these bodies.

Or combustible.

None of the secondary compounds are, properly speaking, combustible. The soaps, indeed, and the vegetable acid salts, are susceptible of undergoing a kind of combustion, but not till they have been previously decomposed by heat; and even then their combustion is not to be compared to that of some of the simple substances and primary compounds. Two genera of salts, namely, the nitrats and hyperoxymuriats, are supporters of combustion in a remarkable degree, occasioning violent detonations when triturated or heated along with combustibles. Many of the metallic salts are doubtless sus-

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ceptible of supporting combustion as well as these genera, though hitherto the experiment has not been tried except upon a small number.

Better known than other bodies.

The secondary compounds have been investigated with more precision than any other class of bodies belonging to chemistry; and their formation and decomposition are more completely in the power of the chemist. The greater number of them may be formed and decomposed at pleasure; and approaches have been made towards ascertaining the proportions of the component parts of several of them. Accordingly it is from them that almost all our notions of the nature of affinity have been derived. It is to them that we have always recourse to illustrate these notions, or to put them to the test of experiment. What have been called *tables of affinity*, are nothing else than lists of the substances by which certain secondary compounds may be decomposed, or of the precipitations which take place when different secondary compounds are mixed together. It was necessary therefore to be acquainted with these bodies, and to know the mutual changes which they are capable of producing on each other; the decompositions of which they are susceptible, and the proportions of their component parts, before entering upon the consideration of *affinity;* which may be considered as constituting in reality the whole of the scientific part of chemistry, and as comprehending under it the general principles to which the immense mass of facts enumerated in the two preceding Books may be referred, and under which they may be arranged. We are now therefore prepared for entering upon this important subject, which will employ the whole of the succeeding Book.

BOOK III.

OF

AFFINITY.

In the two preceding Books the different substances which occupy the attention of the chemists have been enumerated, their properties have been described, and the changes which they produce on each other have been fully detailed. We are thus in possession of the immense body of facts of which the science of chemistry is composed; they have been arranged in that order which seemed most proper for shewing their mutual dependence on each other; and referred to a small number of general heads, that they might be remembered with facility or consulted without difficulty. It were to be wished that chemical phenomena could be referred to a few general laws, and shewn to be the necessary results of these laws. It were to be wished that we knew the nature of these laws so precisely, as to be able to foretel beforehand the changes which result from the mutual action of bodies in every particular circumstance. This would save us the trouble of learning in detail an immense number of insulated facts which

Book III.

Chemical laws

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at present are necessary for the practice of chemistry; it would enable us to apply the science with more effect to the arts and manufactures; it would enable us to trace the chemical changes which are going on in the atmosphere and the earth to their origin, and to foresee the future changes to which they are liable; and thus to form, what has hitherto been attempted in vain, a complete theory of meteorology and geology.

Still imperfectly known.

Unfortunately the efforts of philosophers to establish these general principles have not hitherto been attended with complete success; partly owing to the difficulty of the subject, and partly to the unaccountable negligence of the greater number of chemists, who have been more anxious to ascertain particular facts than to investigate general principles, and who have often seemed to look upon general principles as altogether foreign to their science. Happily this has not been the case with all chemists. Several, and these the most illustrious, have carefully classified the phenomena, and referred them under general heads; and if they have not succeeded in discovering laws sufficiently comprehensive to include all the chemical phenomena, have at least pointed out several pretty general ones, from the knowledge of which the mutual action of many bodies on each other may, in not a few cases, be foreseen, even prior to experiment. Among these philosophers, none stands higher than Bergman, who was not less distinguished by his industry and enthusiasm, than by his enlarged views and the happy acuteness with which he drew general conclusions. To Black and Lavoisier we are indebted for two of the most general and most important laws hitherto discovered in chemistry. Much has been done by Kirwan, whose profound knowledge,

fortunately for the science, almost constantly leads him to general views. Morveau has been no less distinguished in this important career: with a mind capable of the most comprehensive range, and the most profound views, he has classified the most difficult phenomena, and thrown light upon the abstrusest part of the science. And Berthollet has lately reviewed the general doctrines of chemistry with his usual sagacity; and has not only corrected various errors which had passed current without detection, but has pointed out several new laws of very great importance.

The general principles of chemistry will form the subject of this third Book, which will be divided into four Chapters. In the *first* Chapter, we shall consider the nature of AFFINITY in general; in the *second*, we shall examine the affinity which HOMOGENEOUS bodies exert on each other; in the *third*, the affinity exerted by HETEROGENEOUS bodies; and in the *fourth*, the nature of REPULSION, which often acts as an antagonist to affinity.

CHAP. I.

OF AFFINITY IN GENERAL.

Attraction

1. ALL the great bodies which constitute the solar system are urged towards each other by a force which preserves them in their orbits and regulates their motions. This force has received the name of *attraction*. Its nature is unknown: Whether it be inherent in these bodies themselves, or the consequence of some foreign agent, are questions altogether beyond the reach of philosophy, because we have no method of deciding the point. One would be more inclined to the first supposition than to the other, as we can conceive no foreign agent sufficient to explain the planetary motions unless an intelligent one; and for any thing which we know to the contrary, it was as easy for the Creator to have bestowed on the planets the power of acting on each other at a distance, as the power of being acted on and receiving motion from other substances.

Universal.

2. Sir Isaac Newton demonstrated, that this planetary attraction is the same with *gravitation*, or that force by which a heavy body is urged towards the earth; that it is possessed, not only by the planets as wholes, but by all their component parts also; that it is mutual; that it extends to indefinite distances; and that all bodies, as far as is known, are possessed of it.

3. When two bodies are brought within a certain distance, they adhere together, and require a considerable force to separate them. This is the case, for instance, with two polished pieces of marble or glass. When a piece of metal, or indeed almost any body whatever, is plunged into water and drawn out again, its surface is moistened, that is to say, part of the water adheres to it. When a rod of gold is plunged into mercury, it comes out stained indelibly of a white colour, because it retains and carries with it a portion of the mercury. Hence it is evident that there is a force which urges these bodies towards each other and keeps them together; consequently there is an attraction between them. Bodies, therefore, are not only attracted towards the earth and the planetary bodies, but towards each other. The nature of this attraction cannot be assigned any more than that of gravitation; but its existence is equally certain, as far at least as regards by far the greater number of bodies.

4. In all cases we find the particles of matter united together in masses; differing indeed from each other in magnitude, but containing all of them a great number of particles. These particles remain united, and cannot be separated without the application of a considerable force; consequently they are kept together by a force which urges them towards each other, since it opposes their separation. Consequently this force is an *attraction*.

Thus we see that there is a certain unknown force which urges bodies towards each other; a force which acts not only upon large masses of matter, as the sun and the planets, but upon the smaller component parts of these bodies, and even upon the particles of which

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these bodies are composed. Attraction, therefore, as far as we know, extends to all matter, and exists mutually between all matter. It is not annihilated at how great a distance soever we may suppose bodies to be placed from each other, neither does it disappear, though they be placed ever so near each other. The nature of this attraction, or the cause which produces it, is altogether unknown, but its existence is demonstrated by all the phenomena of nature.

Ascribed to impulsion,

5. This attraction was long accounted for, by supposing that there existed a certain unknown substance which impelled all bodies towards each other; a hypothesis to which philosophers had recourse, from an opinion long admitted as a first principle, "that no body can act where it is not;" as if it were more difficult to conceive why a change is produced in a body by another which is placed at a great distance, than why it is produced by one which is situated at a small distance.

But without reason.

It is not only impossible to explain the phenomena of attraction by impulsion, but it is as difficult to conceive how bodies should be urged towards each other by the action of an external substance, as how they should be urged towards each other by a power inherent in themselves. The fact is, that we can neither comprehend the one nor the other; nor can any reason be assigned why the Almighty might not as easily bestow upon matter the power of acting upon matter at a distance, as the power of being acted upon and changed by matter in actual contact.

But farther, we have no reason for supposing that bodies are ever in any case actually in contact. For all bodies are diminished in bulk by cold, that is to say, their particles are brought nearer each other, which

would be impossible, unless they had been at some distance before the application of the cold. Almost all bodies are diminished in bulk by pressure, and consequently their particles are brought nearer each other; and the diminution of bulk is always proportional to the pressure. Newton has shown that it required a force of many pounds to bring two glasses within the 8ooth part of an inch of each other; that a much greater was necessary to diminish that distance; and that no pressure whatever was capable of diminishing it beyond a certain point. Consequently there is a force which opposes the actual contact of bodies; a force which increases inversely as some power or function of the distance, and which no power whatever is capable of overcoming. Boscovich has demonstrated, that a body in motion communicates part of its motion to another body before it actually reaches it. Hence we may conclude that, as far as we know, there is no such thing as actual contact in nature, and that bodies of course always act upon each other at a distance. Even impulsion, therefore, or pressure, is an instance of bodies acting on each other at a distance, and therefore is no better explanation of attraction than the supposition that it is an inherent power. We must therefore be satisfied with considering attraction as an unknown power, by which all bodies are urged towards each other. It is a power which acts constantly and uniformly in all times and places, and which is always diminishing the distance between bodies, unless when they are prevented from approaching each other by some other force equally powerful.

Of two kinds.

6. The change which attraction produces on bodies is a diminution of their distance. Now the distances of

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bodies from each other are of two kinds, either too small to be perceived by our senses, or great enough to be easily perceived and estimated. In the first case, the change of distance produced by attraction must be insensible; in the second case it must be visible. Hence the attractions of bodies, as far as regards us, naturally divide themselves into two classes. 1. Those which act at sensible distances. 2. Those which act at insensible distances. The first class obviously applies to bodies in masses of sensible magnitude; the second class must be confined to the particles of bodies, because they alone are at insensible distances from each other.

1. At sensible distances.

7. It has been demonstrated, that the intensity of the first class of attractions varies with the mass and the distance of the attracting bodies. It increases with the mass of these bodies, but diminishes as the distance between them increases. Hence we see that in this class of attractions every particle of the attracting bodies acts, since the sum of the attracting force is always proportional to the number of particles in the attracting bodies. Why it diminishes as the distance increases, it is impossible to say; but the fact is certain, and is almost incompatible with the supposition of impulsion as the cause of attraction. The rate of variation has been demonstrated to be inversely as the square of the distance in all cases of attraction belonging to the first class.

8. The attractions belonging to the first class must be as numerous as there are bodies situated at sensible distances; but it has been ascertained that they may be all reduced to three different kinds; namely, 1. Gravitation; 2. Electricity; 3. Magnetism. The first of these has been shewn by Newton to belong to all matter, as far as we have an opportunity of examining, and

therefore to be universal. The other two are partial, being confined to certain sets of bodies, while the rest of matter is destitute of them; for it is well known that all bodies are not electric, and that scarcely any bodies are magnetic, except iron, cobalt, nickel, and perhaps manganese.

The intensity of these three attractions increases as the mass of the attracting bodies, and diminishes as the square of the distance increases. The first extends to the greatest distance at which bodies are known to be separated from each other. How far electricity extends has not been ascertained; but magnetism extends at least as far as the semidiameter of the earth. All bodies possess gravity; but it has been supposed that the other two attractions are confined to two or three subtile fluids, which constitute a part of all those bodies which exhibit the attractions of electricity or magnetism. This may be so; but it has not, and scarcely can be demonstrated.

9. The absolute force of these attractions in given bodies can only be measured by the force necessary to counteract the effect of these attractions, or by the space which given bodies, acted on merely by these attractions, traverse in a given time. If we compare the different bodies acted on by gravitation, we shall find that the absolute force of their gravitation towards each other is in all cases the same, provided their distances from each other and their mass be the same; but this is by no means the case with electrical and magnetic bodies. In them the forces by which they are attracted towards each other, called electricity and magnetism, are exceedingly various, even when the mass and the distance are the same. Sometimes these forces disap-

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pear almost entirely; at other times they are exceedingly intense. Gravity therefore is a force inherent in bodies; electricity and magnetism not so; a circumstance which renders the opinion of their depending upon peculiar fluids exceedingly probable. If we compare the absolute force of these three powers with each other, it would appear that the intensity of the two last, every thing else being equal, is greater than that of the first; but their relative intensity cannot be compared, and is therefore unknown. Hence it follows that these different attractions, though they follow the same laws of variation, are not the same in kind.

2. Affinity.

10. The attractions between bodies at insensible distances, and which of course are confined to the particles of matter, have been distinguished by the name of *affinity*, while the term *attraction* has been more commonly confined to cases of sensible distance. Now the particles of matter are of two kinds, either *homogeneous* or *heterogeneous*. By homogeneous particles, I mean particles which compose the same body; thus all particles of iron are homogeneous. By heterogeneous particles are meant those which compose different bodies; thus a particle of iron and a particle of lead are heterogeneous.

Homogeneous affinity urges the homogeneous particles towards each other, and keeps them at insensible distances from each other; and consequently is the cause why bodies almost always exist united together, so as to constitute masses of sensible magnitude. This affinity is usually denoted by the term *cohesion*, and sometimes by *adhesion* when the surfaces of bodies are only referred to. Homogeneous affinity is nearly universal; as far as is known, caloric and light only are destitute of it.

Heterogeneous affinity urges heterogeneous particles towards each other, and keeps them at insensible distances from each other, and of course is the cause of the formation of new integrant particles composed of a certain number of heterogeneous particles. These new integrant particles afterwards unite by cohesion, and form masses of compound bodies. Thus an integrant particle of water is composed of particles of hydrogen and oxygen, urged towards each other, and kept at an insensible distance by heterogeneous affinity; and a mass of water is composed of an indefinite number of integrant particles of that fluid, urged towards each other by homogeneous affinity. Heterogeneous affinity is universal, as far as is known; that is to say, there is no body whose particles are not attracted by the particles of some other body; but whether the particles of all bodies have an affinity for the particles of all other bodies, is a point which we have no means of ascertaining. It is, however, exceedingly probable, and has been generally taken for granted; though it is certainly assuming more than even analogy can warrant.

Increases with the mass.

11. Affinity, like sensible attraction, varies with the mass and the distance of the attracting bodies. That cohesion varies with the mass, cannot indeed be ascertained; because we have no method of varying the mass without at the same time altering the distance. But in cases of the adhesion of the surfaces of homogeneous bodies, which is undoubtedly an instance of homogeneous affinity, it has been demonstrated, that the force of adhesion increases with the surface, that is to say, with the mass; for the number of adhering particles must increase with the surface.

That heterogeneous affinity increases with the mass,

Book III. has been observed long ago in particular instances, and has been lately demonstrated by Berthollet to hold in every case: thus a given portion of water is retained more obstinately by a large quantity of sulphuric acid than by a small quantity. Oxygen is more easily abstracted from those oxides which are oxidized to a maximum, than from those which are oxidized to a minimum; that is to say, that a large mass of metal retains a given quantity of oxygen more violently than a small mass. Lime deprives potass of only a portion of its carbonic acid, and sulphuric acid deprives phosphoric acid of only a portion of the lime with which it is united in phosphat of lime. In these, and many other instances that might be enumerated, a small portion of one body is retained by a given quantity of another more strongly than a large quantity. And Berthollet has shewn, that in all cases a large quantity of a body is capable of abstracting a portion of another from a small portion of a third; how weak soever the affinity between the first and second of these bodies is, and how strong soever the affinity between the second and the third. Thus when equal quantities of the following bodies were boiled together,

1. { Sulphat of barytes / Potass
2. { Sulphat of potass / Soda
3. { Sulphat of potass / Lime
4. { Oxalat of lime / Potass
5. { Phosphat of lime / Potass
6. { Carbonat of lime / Potass

the uncombined base abstracted part of the acid from the base with which it was previously combined; tho' in every one of these instances it was retained by that base by an affinity considered as stronger. The same

division of the base took place when equal quantities of oxalat of lime and nitric acid were boiled together.

Inversely as the distance.

That the force of affinity increases as the distance diminishes, and the contrary, is obvious; for it becomes insensible whenever the distance is sensible, and on the other hand, becomes exceedingly great when the distance is exceedingly diminished. But the particular rate which this variation follows is still unknown, as we have no method of measuring either the distances at which it acts, or its relative intensity at these distances. Some have supposed that it follows a greater ratio than $\frac{1}{d^2}$, and that it diminishes at least as $\frac{1}{d^3}$, if not at some greater rate. But their reasoning has depended altogether upon the supposition that the particles of bodies united by affinity are in actual contact and loses its force, or at least a considerable part of it, if we suppose, what seems actually to be the case, that even then these particles are at a distance. Others have supposed that the intensity of affinity varies inversely as the square of the distance, resting chiefly upon the analogy of sensible attraction which follows that law. This is certainly a kind of presumption in favour of the opinion, and it must be allowed that no sufficient arguments have been advanced to prove that this law is incompatible with the phenomena of affinity. But neither, on the other hand, have any thing like proofs been advanced to show that affinity actually varies according to that law. The truth is, that at present the subject is beyond the reach of philosophy. We must therefore suspend our judgment altogether till future discoveries put it in our power to determine the point.

12. Affinity then agrees with sensible attraction in

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every point which it has been hitherto possible to determine. Like sensible attraction, it increases with the mass, and diminishes as the distance augments; consequently we must conclude that attraction, whether it be sensible or insensible, is in all cases the same kind of force, and regulated by precisely the same general laws.

We have seen that sensible attraction, though in all cases the *same kind* of force, is not always the *very same* force; for though the mass and the distance of two bodies be equal, the absolute force by which they are attracted towards each other by gravitation is not equal to the force by which they are attracted towards each other by magnetism. The forces of sensible attraction are three in number, namely, gravitation, magnetism, and electricity; the first is always the same when the mass and distance are the same, but the two last vary even when the mass and distance continue unaltered.

Affinity varies in intensity.

The forces of affinity, though also the same in kind, are still more numerous than those of sensible attraction; for instead of three, they amount to as many as there are heterogeneous bodies. The rate, indeed, at which they vary when the distance of the attracting bodies increases or diminishes, is probably the same in all, and so is also their variation as far as it regards the mass. But even when both of these circumstances, as far as we can estimate them, are the same, the affinity of two bodies for a third is not the same. Thus barytes has a stronger affinity for sulphuric acid than potass has: for if equal quantities of each be mixed with a small portion of sulphuric acid, the barytes seizes a much greater proportion of the acid than the potass does. This difference in intensity extends to particles of all

bodies; for there are scarcely any two bodies whose particles have precisely the same affinity for a third, and scarcely any two bodies, the particles of each of which cohere together with exactly the same force.

It is this difference in intensity which constitutes the most important characteristic mark of affinity, and which explains the different decompositions and changes which one body occasions in others.

Thus it appears at first sight, that there are as many different affinities as there are bodies; and that affinity, instead of being one force like gravitation, which is always the same when the circumstances are the same, consists of a variety of different forces, regulated, indeed, by the same kind of laws, but all of them different from each other. These affinities do not vary like magnetism and electricity, though the mass continues the same, but are always of equal intensity when other circumstances are equal. Hence it is reasonable to conclude that these affinities cannot, like magnetism and electricity, depend upon peculiar fluids, the quantity of which may vary, but that they are permanent forces, inherent in every atom of the attracting bodies.

13. It is very possible that this variation of intensity, which forms so remarkable a distinction between affinity and gravitation, may be only apparent and not real. For even in gravitation the intensity varies with the distance and the mass, and the same variation holds in affinity. But as the attraction of affinity acts upon bodies situated at insensible distances from each other, it is evident that, strictly speaking, we have no means of ascertaining that distance, and consequently that it may vary without our discovering the variation. But every such variation in distance must occasion a correspond-

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ing variation in the intensity of the attracting force. It may be then that barytes attracts sulphuric acid with greater intensity than potass, because the particles of barytes, when they act upon the acid, are at a smaller distance from it than the particles of the potass are.

Owing perhaps to the figure of the particles.

But it may be asked, Why, if barytes, potass, and sulphuric acid, are all mixed together in water, the particles of potass do not approach as near the acid as those of the barytes, since they are both at liberty to act? To this it may be answered, That in all probability they do approach each of them to the same *apparent* distance (if the expression be allowable), but that, notwithstanding, their *real* distance may continue different. The particles of bodies, how minute soever we suppose them to be, cannot be destitute of magnitude. They must have a certain length, breadth, and thickness, and therefore must always possess some particular figure or other. These particles, indeed, are a great deal too minute for us to detect their shape; but still it is certain that they must have some shape. Now it is very conceivable that the particles of every particular body may have a shape peculiar to themselves, and differing from the shape of the particles of every other body. Thus the particles of sulphuric acid may have one shape, those of barytes another, and those of potass a third.

But if the particles of bodies have length, breadth, and thickness, we cannot avoid conceiving them as composed of an indeterminate number of still more minute particles or atoms. Now the affinity of two integrant particles for each other must be the sum of the attractions of all the atoms in each of these particles for all the atoms in the other: But the sum of these

attractions must depend upon the number of attracting atoms, and upon the distance of these atoms from each other respectively; and this distance must depend upon the figure of the particles. For it is obvious, that if two particles, one of which is a tetrahedron and the other a cube, and which contain the same number of atoms, be placed at the same relative distance from a third particle, the sum of the distances of all the atoms of the first particle from all the atoms of the third particle, will be less than the sum of the distances of all the atoms of the second particle from those of the third. Consequently, in this case, though the apparent distance of the particles be the same, their real distance is different; and of course the cube will attract the third particle more strongly than the tetrahedron; that is, it will have a greater affinity for it than the tetrahedron.

But if the particles of bodies differ from each other in figure, they may differ also in density and in size: and this must also alter the absolute force of affinity, even when the distances and the figure of the attracting particles are the same. The first of these two circumstances indeed may be considered as a difference in the mass of the attracting bodies, and therefore may be detected by the weight of the aggregate; but the second, though also no less a variation in the mass, cannot be detected by any such method, though its effect upon the strength of affinity may be very considerable.

There is no doubt that, upon the supposition that such differences in the figure, density, and size of the attracting particles, really exist, and it is in the highest degree probable that they do exist, the variation in intensity which characterises chemical affinity may be

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accounted for, without supposing that the intensity of affinity as a force inherent in the ultimate particles or atoms of bodies is really different. The same thing may be applied to electricity and magnetism. It is certainly possible, therefore, that attraction, both sensible and insensible, may not only vary at the same rate, and according to the same laws, but be absolutely the same force inherent in the atoms of matter, modified merely by the number and situation of the attracting atoms. This is certainly possible; and it must be allowed that it corresponds well with those notions of the simplicity of Nature in which we are accustomed to indulge ourselves. But the truth is, that we are by no means good judges of the simplicity of Nature; we have but an imperfect glimpse here and there through the veil with which her operations are covered; and from the few points which we see, we are constantly forming conjectures concerning the whole of the machinery by which these operations are carried on. Superior beings smile at our theories as we smile at the reasonings of an infant; and were the veil which conceals the machine from our view to be suddenly withdrawn, we ourselves, in all probability, would be equally astonished and confounded at the wide difference between our theories and conjectures, and the real powers by which the machinery of the universe is moved. Let us not therefore be too precipitate in drawing general conclusions; but let us rather wait with patience till future discoveries enable us to advance farther; and satisfy ourselves in the mean time with arranging those laws of affinity which have been ascertained, without deciding whether it be the same force with gravitation, or a different one.

May be the same with gravitation.

14. The characteristic marks of affinity may be reduced to the three following:

I. It acts only at insensible distances, and of course affects only the particles of bodies.

II. This force is always the same in the same particles, but it is different in different particles.

III. This difference is modified considerably by the mass. Thus though A have a greater affinity for C than B has, if the mass of B be considerably increased while that of A remains unchanged, B becomes capable of taking a part of C from A.

But it will be necessary to consider the affinity of homogeneous and heterogeneous bodies more particularly. This will be the subject of the two following Chapters.

CHAP. II.

OF HOMOGENEOUS AFFINITY.

We never find the particles of bodies in a separate state: they are either combined with the particles of other bodies, or with each other, forming masses of greater or smaller magnitude. This last union is the effect of homogeneous affinity; which has been already defined to mean that force which unites homogeneous particles to each other. Now in homogeneous affinity there are two things which claim our attention: The first is the force itself by which the particles are kept united; the second is the form which the particles thus united are known to assume. The force is distinguished by the title of *cohesion;* and the form of the mass, when regular, has received the name of *crystal.* These two topics shall form the subjec of the two following Sections, under the titles of *Cohesion* and *Crystallization.*

SECT. I.

OF COHESION.

THE force called *cohesion* is inherent in all the particles of all bodies, if we except caloric and light: For all bodies except these constantly exist in masses composed of an indefinite number of particles united together. This force possesses all the characters of affinity.

1. It acts only at insensible distances; for whenever we remove the particles of a body to a perceptible distance from each other, they cease to cohere altogether.

2. Cohesion is exceedingly various in different bodies: though in the same body, if other things be equal, it is always the same. Thus an iron rod is composed of particles of iron cohering so strongly, that it requires an enormous force to separate them. A smaller force is necessary to overcome the cohesion of lead, and a still smaller to separate the particles of chalk from each other. In short, there are scarcely two bodies whose particles cohere with the same force. The force of cohesion in solid bodies is measured by the weight necessary to break them, or rather to pull them asunder. Thus if a rod of glass be suspended in a perpendicular direction, and weights be attached to its lower extremity till the rod is broken by them, the weight attached to the rod just before it broke is the measure of the cohesive force of the rod. We are indebted to Muschenbroeck for the most complete set of experiments hither-

Cohesion varies in different bodies.

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to made upon the cohesive force of solid bodies. Sickengen has also examined the cohesion of several of the metals with much accuracy. The results of the labours of the first of these philosophers may be seen in the following TABLE *:

I. METALS.

Steel, bar	135,000
Iron, bar	74,500
Iron, cast	50,100
Copper, cast	28,600
Silver, cast	41,500
Gold, cast	22,000
Tin, cast	4,440
Bismuth	2,900
Zinc	2,600
Antimony	1,000
Lead, cast	860

II. ALLOYS.

Gold 2 parts, silver 1 part	28,000
Gold 5, copper 1	50,000
Silver 5, copper 1	48,500
Silver 4, tin 1	41,000
Copper 6, tin 1	55,000
Brass	51,000
Tin 3, lead 1	10,200
Tin 8, zinc 1	10,000
Tin 4, antimony 1	12,000
Lead 8, zinc 1	4,500
Tin 4, lead 1, zinc 1	13,000

* In this Table the numbers denote the pounds avoirdupois which are just sufficient to tear asunder a rod of each of the bodies whose base is an inch square.

III. Woods.

Locust tree	20,100
Jujeb	18,500
Beech, oak	17,300
Orange	15,500
Alder	13,900
Elm	13,200
Mulberry	12,500
Willow	12,500
Ash	12,000
Plum	11,800
Elder	10,000
Pomegranate	9,750
Lemon	9,250
Tamarind	8,750
Fir	8,330
Walnut	8,130
Pitch pine	7,656
Quince	6,750
Cypress	6,000
Poplar	5,500
Cedar	4,880

IV. Bones.

Ivory	16,270
Bone	15,250
Horn	8,750
Whalebone	7,500
Tooth of sea calf	4,075

Explained by Boscovich.

3. The nature of cohesion has been more happily explained by Boscovich than by any other philosopher. Indeed it forms the most beautiful and satisfactory part

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of his theory. According to him, the particles of bodies cohere together when they are placed in the limit of repulsion and attraction. Two particles, when situated at a certain distance from each other, repel each other mutually; this repulsion gradually diminishes as the distance between the particles increases, till at last when the distance reaches a certain magnitude, the repulsion ceases altogether. If the distance be increased ever so little, the particles now, instead of repelling, attract each other; and this attraction increases with the distance, till at last it reaches its maximum. From this point it gradually diminishes, till at last, when the particles have acquired a certain distance, it vanishes altogether. If the distance be increased ever so little beyond that distance, the particles now again repel each other. He supposes that the insensible distance between two particles is divided into an indefinite number of portions of alternate repulsions and attractions.

Let the line AH (fig. 14.) represent the insensible distance between two particles; and let the ordinates of the curve IQ q q' q'' represent the attracting and repelling forces of the two particles as the second moves along the line AB while the first remains in the point A. The ordinates of the curves situated above the line AH represent repulsive forces, and those below the line represent attracting forces. The points B, C, D, E, F, G, H, where the curve cuts the axis, represent the limits between repulsion and attraction. While the second particle is in any part of the line AB it is repelled: the repulsion increases as the particle approaches A; and at the point A it is infinite, because the line Aa is to be considered as an asymptote to the

curve. At the point B the second particle is neither repelled nor attracted. In every part of the line BC it is attracted; and the attraction is a maximum at P, because there the ordinate PQ is a maximum. At the point C it is neither attracted nor repelled. In every part of CD it is repelled; in D it is neither attracted nor repelled; in DE it is attracted, and so on.

Now the points B, D, F, and H, are called by Boscovich limits of cohesion, because particles placed in these points remain unaltered, and even resist any force which endeavours to displace them. If they are driven nearer each other, they are again repelled to their former limit: on the other hand, if they are driven to a greater distance, they are again attracted to their former situation.

Boscovich supposes, that in all cases of cohesion the particles of the cohering body are so situated as to be in these limits of cohesion with respect to each other. According to this very ingenious theory, cohesion is not, properly speaking, a force, but the interval between two forces. And even if we were to modify the theory a little, still we must consider cohesion as the balancing of two opposite forces, either of which becomes prevalent according as the cohering particles are urged nearer each other or forced to a greater distance. Consequently if we were to speak with precision, *cohesion* is not itself a force, but the absence of a force. What has been hitherto called the *force of cohesion*, is the attraction which prevents the cohering particles from separating from each other, and which begins to act; or, more precisely, which becomes prevalent when the particles are urged to a greater distance from each other.

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4. Boscovich has shewn, in a very satisfactory manner, how all the varieties of cohesion may be produced by the differences in the size, figure, and density, of the cohering particles *. It deserves attention, that in most cases the cohesive force of simple bodies is greater than that of compound bodies. To this indeed there are a great number of exceptions, but the observation holds in a variety of instances. All the metals cohere very strongly; the diamond probably coheres with no less force, if we can judge from its hardness; and the cohesion of sulphur is also very considerable. Thus if we except phosphorus, all the simple substances are remarkable for cohesion. Those of them which are in the state of elastic fluids must be excluded altogether; because in that particular state the particles, instead of being in the limit of cohesion, are actually repelled. In the earths, too, such of them at least as are found crystallized in a state of purity, the cohesion is very strong. Thus the sapphire or crystallized alumina, and rock crystal or crystallized silica, are always very hard, and exhibit a much stronger cohesion than limestone, or magnesian stones, which are composed of heterogeneous bodies. This remark, however, by no means applies to the metals; for in them the cohesion is very often increased considerably by alloying them together. Thus the cohesion of copper is doubled by alloying it with one-sixth of its weight of tin, though the cohesion of the tin is scarcely one-sixth of that of the copper.

The cohesion of metals is greatly increased by forging them, and by drawing them out into wire. By this last operation gold, silver, and brass, have their

* See his *Theoria Philosophiæ Naturalis*, Part iii, Sect. 406. p. 185.

cohesion nearly tripled; copper and iron more than doubled.

5. There are three states in which bodies exist exceedingly distinct from each other; the state of solids, of liquids, and of elastic fluids. In the two first states the particles cohere with more or less force; but the cohesion produces in them very different effects. In the first it prevents all relative motion among the particles themselves; in the second, this relative motion is left at full liberty. Hence in solid bodies the motion of one particle is followed by the motion of the whole mass; or if that is impossible, the cohesion is destroyed altogether. In liquids, on the contrary, the motion of one particle is not necessarily followed by that of the rest, neither does that motion destroy the cohesion. Boscovich has shewn, that solidity and fluidity are the consequence of the figure of the cohering particles. If that figure is such that the particles may change their position without altering their relative distances, the consequence must be fluidity; because in that case there is nothing to oppose the motion of any individual particle. This happens when the particles are spherical; but if the figure be such that the particles cannot change their position without altering their relative distances, the bodies which they compose must be solids, because all relative motion of an individual particle is opposed by the attractions and repulsions of all the surrounding particles; for every motion must bring the particle out of the former limit of cohesion. This happens when the particles have the figure of parallelopipeds, or any other figure except that of spheres.

This explanation is exceedingly ingenious; but it would not be an easy task to explain by means of it all

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the phenomena of solidity and fluidity. How comes it, for instance, that the addition of a certain dose of caloric renders a body fluid which was before solid? If it be answered, that it acts by combining with the particles of the solid in such a manner as to render them spherical; how comes it, in that case, that gold and platinum, metals which are ductile and malleable, properties which indicate a kind of approach to fluidity, and of course to sphericity, in the particles of these metals—how comes it that they require so much more caloric to render them fluid than bismuth or sulphur, which are altogether brittle? We must rather consider fluidity as a kind of solution in caloric, analogous to the solution of salts in water. But this explanation, tho' it would do very well in many instances, would lead us in others to difficulties as great as those which we are endeavouring to avoid.

The cohesion of liquids is often very considerable. According to Sir Isaac Newton, it is nearly proportional to the density of the liquid. This holds pretty accurately in several instances: but it is not easy to ascertain the cohesion of a liquid with precision, because the particles slide upon each other, and the column of the liquid, whose cohesion we are measuring, always becomes smaller and smaller, till at last it consists only of a very small number of particles.

Viscid bodies have particles approaching to a spherical form; but deviating from it so far as to occasion a certain resistance to the relative motion of the particles.

Solid bodies are of two kinds: they may either resist all change of distance in their particles so strongly as not to be capable of compression or dilatation with-

out a breach of cohesion; or they may admit of both to a certain degree with facility. The first of these constitutes hardness; the second constitutes softness, if the particles retain their new situation, or elasticity if they return again to their old position when the external force is removed *. Ductility and malleability depend upon the same state as softness, only the particles require a greater force to make them change their situation and assume a new one.

Solution.

6. When a solid body is plunged into a liquid, if the particles of the liquid attract those of the solid with a greater force than these last particles attract each other, they are gradually carried off by the fluid, and combine with its particles, that is to say, the solid is gradually dissolved. Thus sugar is dissolved by water, and sulphur by oil. The particles of the solid thus dissolved are each of them surrounded and combined with a certain number of the particles of the liquid. Hence they must be arranged in the liquid in regular order, and at regular distances from each other. The greater number of particles thus dissolved by the liquid, the smaller is the affinity by which each of them is retained, because it is surrounded by a smaller number of particles of the liquid. But the greater must be the force with which these particles are attracted towards each other, and of course tend to form the solid again by cohesion; because the greater the number of the particles of the solid dissolved in the fluid, the nearer are they to each other.

Thus it appears that the affinity between the fluid

* Boscovich, *Theoria Naturalis*, p. 199.

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and solid diminishes with the quantity dissolved; but that the tendency to cohesion increases with that quantity. Consequently if the solution be supposed to go on, these two opposite forces must at last balance one another. And whenever that happens, the liquid can dissolve no more of the solid. If it did, the particles of the solid would in part cohere, and form a new portion of the solid again. Whenever this happens, the fluid is said to be *saturated*. The saturation of a fluid then does not mean that its affinity for the solid is satisfied, but that it is not greater than the tendency of the combined particles to cohere. Now, when a liquid is saturated with a solid, if by any means we can abstract part of that liquid, the cohesive force of the particles of the solid must gain the superiority; and the consequence will be, that they will unite and form solid bodies anew, till their number be so much diminished, that their mutual attraction is again counterbalanced by the affinity of the liquid. Hence the reason that evaporation occasions the crystallization of those bodies which are held in solution by liquids.

7. These different solid bodies differ excessively from each other in their tendency to cohesion; and this difference can only be ascertained by experiment. Thus the tendency to cohesion, and the force of cohesion in silica, is so strong, that when it has been precipitated from a solution by evaporation, it cannot be dissolved again in the same liquid.

This tendency to cohesion, and the consequent insolubility of the compound, produce many of the most important phenomena of chemistry, as they occasion the various precipitations and decompositions which so often take place when different substances are mixed to-

gether. But this subject belongs more properly to the next Chapter, in which it will be necessary to point out the effect of cohesion as an antagonist to heterogenous affinity. Let us proceed, therefore, to consider the forms which bodies assume when their particles have full liberty to unite themselves by cohesion.

SECT. II.

OF CRYSTALLIZATION.

THE word *crystal* (κρυστάλλος) originally signified *ice*; but it was afterwards applied by the ancients to crystallized silica, or *rock crystal;* because, as Pliny informs us, they considered that body as nothing else than water congealed by the action of cold. Chemists afterwards applied the word to all transparent bodies of a regular shape; and at present it is employed to denote in general the regular figures which bodies assume when their particles have full liberty to combine according to the laws of cohesion. These regular bodies occur very frequently in the mineral kingdom, and have long attracted attention on account of their great beauty and regularity. By far the greater number of the salts assume likewise a crystalline form; and as these substances are mostly soluble in water, we have it in our power to give the regular shape of crystals in some measure at pleasure.

1. All the substances with which we are acquainted may be divided into solid, liquid, and gaseous. Crystals

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are obviously confined to the first set, the fluidity of the two last rendering them incapable of retaining a regular form; but many of them may be made to assume a solid state, and in that case they usually crystallize. Most solid bodies either occur in the state of crystals, or are capable of being made to assume that form. Now it has long been observed by chemists and mineralogists, that there is a particular form which every individual substance always affects when it crystallizes: this indeed is considered as one of the best marks for distinguishing one substance from another. Thus common salt is observed to assume the shape of a cube, and alum that of an octahedron, consisting of two four-sided pyramids, applied base to base. Saltpetre affects the form of a six-sided prism; and sulphat of magnesia that of a four sided prism; and carbonat of lime is often found in the state of a rhomboid. Not that every individual substance always uniformly crystallizes in the same form; for this is liable to considerable variations, according to the circumstances of the case; but there are a certain number of forms peculiar to every substance, and the crystals of that substance, in every case, adopt one or other of these forms, and no other; and thus common salt, when crystallized, has always either the figure of a cube or octahedron, or some figure reducible to these.

Crystals formed by

2. As the particles of bodies must be at liberty to move before they crystallize, it is obvious that we cannot reduce any bodies to the state of crystals, except those which we are able to make fluid. Now there are two ways of rendering bodies fluid, namely, solution in a liquid, and fusion by heat. These of course are the only methods of forming crystals in our power.

Solution is the common method of crystallizing salts. They are dissolved in the water: the water is slowly evaporated, the saline particles gradually approach each other, combine together, and form small crystals; which become constantly larger by the addition of other particles, till at last they fall by their gravity to the bottom of the vessel. It ought to be remarked, however, that there are two kinds of solution, each of which presents different phenomena of crystallization. Some salts dissolve in very small proportions in cold water, but are very soluble in hot water; that is to say, water at the common temperature has little effect upon them, but water combined with caloric dissolves them readily. When hot water saturated with any of these salts cools, it becomes incapable of holding them in solution: the consequence of which is, that the saline particles gradually approach each other and crystallize. Sulphat of soda is a salt of this kind. To crystallize such salts nothing more is necessary than to saturate hot water with them, and set it by to cool. But were we to attempt to crystallize them by evaporating the hot water, we should not succeed; nothing would be procured but a shapeless mass. Many of the salts which follow this law of crystallization combine with a great deal of water; or, which is the same thing, many crystals formed in this manner contain a great deal of water of crystallization.

There are other salts again which are nearly equally soluble in hot and cold water; common salt for instance. It is evident that such salts cannot be crystallized by cooling; but they crystallize very well by evaporating their solution while hot. These salts generally contain but little water of crystallization.

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There are many substances, however, neither soluble in water nor other liquids, which, notwithstanding, are capable of assuming a crystalline form. This is the case with the metals, with glass, and some other bodies. The method employed to crystallize them is *fusion*, which is a solution by means of caloric. By this method the particles are separated from one another; and if the cooling goes on gradually, they are at liberty to arrange themselves in regular crystals.

3. To obtain large artificial crystals of a regular shape requires considerable address and much patient attention. This curious branch of practical chemistry has been much improved by Mr Leblanc; who has not only succeeded in obtaining regular crystals of almost any size at pleasure, but has made many interesting observations on crystallization in general *. His method is as follows: The salt to be crystallized is to be dissolved in water, and evaporated to such a consistency that it shall crystallize on cooling. Set it by, and when quite cold pour the liquid part of the mass of crystals at the bottom, and put it into a flat-bottomed vessel. Solitary crystals form at some distance from each other, and these may be observed gradually increasing. Pick out the most regular of these, and put them into a flat-bottomed vessel at some distance from each other, and pour over them a quantity of liquid obtained in the same way, by evaporating a solution of the salt till it crystallizes on cooling. Alter the position of every crystal once at least every day with a glass rod, that all the faces may be alternately exposed to the ac-

* *Jour. de Phys.* lv. 300.

tion of the liquid: for the face on which the crystal rests never receives any increment. By this process the crystals gradually increase in size. When they have acquired such a magnitude that their form can easily be distinguished, the most regular are to be chosen, or those having the exact shape which we wish to obtain; and each of them is to be put separately in a vessel filled with a portion of the same liquid, and turned in the same manner several times a day. By this treatment they may be obtained of almost any size we think proper. After the crystal has continued in the liquid for a certain time, the quantity of salt held in solution becomes so much diminished, that the liquid begins to act upon the crystal and redissolve it. This action is first perceptible on the angles and edges of the crystal. They become blunted, and gradually lose their shape altogether. Whenever this begins to be perceived, the liquid must be poured off, and a portion of new liquid put in its place; otherwise the crystal is infallibly destroyed. Mr Leblanc has observed, that this singular change begins first at the surface of the liquid, and extends gradually to the bottom; so that a crystal, if large, may be often perceived in a state of increase at its lower end, while it is disappearing at its upper extremity. Mr Leblanc even affirms that saline solutions almost always increase in density according to their depth from the surface.

4. It has been observed, that those salts which crystallize upon cooling, do not assume a crystalline form so readily if they are allowed to cool in close vessels. If a saturated solution of sulphat of soda, for instance, in hot water, be put into a phial, corked up closely, and allowed to cool without being moved, no crystals

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are formed at all; but the moment the glass is opened, the salt crystallizes with such rapidity that the whole of the solution in a manner becomes solid. This phenomenon has been explained by supposing that there is an affinity between the salt and caloric, and that while the caloric continues combined with it the salt does not crystallize; that the caloric does not leave the salt so readily when external air is not admitted, as glass receives it very slowly and parts with it very slowly. In short, the atmospherical air seems to be the agent employed to carry off the caloric: a task for which it is remarkably well fitted, on account of the change of density which it undergoes by every addition of caloric. This is confirmed by the quantity of caloric which always makes its appearance during these sudden crystallizations. This explanation might be put to the test of experiment, by putting two solutions of sulphat of soda in hot water in two similar vessels; one of glass, the other of metal, and both closed in the same manner. If the salt contained in the metallic vessel crystallized, which ought to be the case on account of the great conducting power of metals, while that in the glass vessel remained liquid, this would be a confirmation of the theory, amounting almost to demonstration. On the contrary, if both solutions remained liquid, it would be a proof that the phenomenon was still incompletely understood.

Not only salts, but water itself, which commonly crystallizes at 32°, may be made to exhibit the same phenomenon: it may be cooled much lower than 32° without freezing. This, as Dr Black has completely proved, depends entirely upon the retention of caloric.

5. The phenomena of crystallization seem to have at-

Nature of crystallization.

tracted but little of the attention of the ancient philosophers. Their theory, indeed, that the elements of bodies possess certain regular geometrical figures, may have been suggested by these phenomena; but we are ignorant of their having made any regular attempt to explain them. The schoolmen ascribed the regular figure of crystals to their substantial forms, without giving themselves much trouble about explaining the meaning of the term. This notion was attacked by Boyle; who proved, that crystals are formed by the mere aggregation of particles *. But it still remained to explain, why that aggregation took place; and why the particles united in such a manner as to form regular figures?

The aggregation is evidently the consequence of that attractive force which has been examined in the last Section. But to explain the cause of the regular figures is a more difficult task. Newton has remarked, that the particles of bodies, while in a state of solution, are arranged in the solvent in regular order and at regular distances; the consequence of which must be, that when the force of cohesion becomes sufficiently strong to separate them from the solvent, they will naturally combine in groups, composed of those particles which are nearest each other. Now all the particles of the same body must be supposed to have the same figure; and the combination of a determinate number of similar bodies must produce similar figures. Hauy has made it exceedingly probable that these integrant particles always combine in the same body in the same way, that is to say, that the same faces, or the same edges, always

* *Treatise on the Origin of Forms and Qualities.*

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attach themselves together; but that these differ in different crystals. This can scarcely be accounted for, without supposing that the particles of bodies are endowed with a certain polarity which makes them attract one part of another particle and repel the other parts. This polarity would explain the regularity of crystallization; but it is itself inexplicable.

It is remarkable that crystals not only assume regular figures, but are always bounded by plane surfaces. It is very rarely indeed that curve surfaces are observed in these bodies; and when they are, the crystals always give unequivocal proofs of imperfection. But this constant tendency towards plane surfaces is inconceivable, unless the particles of which the crystals are composed are themselves regular figures, and bounded by plane surfaces.

6. If the figure of crystals depends upon the figure of their integrant particles, and upon the manner in which they combine, it is reasonable to suppose that the same particles, when at full liberty, will always combine in the same way, and consequently that the crystals of every particular body will be always the same. Nothing at first sight can appear farther from the truth than this. The different forms which the crystals of the same body assume are often very numerous, and exceedingly different from each other. Carbonat of lime, for instance, has been observed crystallized in no fewer than forty different forms, fluat of lime in eight different forms, and sulphat of lime in nearly an equal number.

All crystals have a primitive form.

But this inconsistency is not so great as might at first sight appear. Romé de Lisle has shown that every body susceptible of crystallization has a particular form

which it most frequently assumes, or at least to which it most frequently approaches. Bergman has demonstrated, that this primitive form, as Hauy has called it, very often lies concealed in those very crystals which appear to deviate farthest from it. And Hauy has demonstrated, that all crystals either have this primitive form, or at least contain it as a nucleus within them; for it may be extracted out of all of them by a skilful mechanical division.

Happening to take up a hexangular prism of calcareous spar, or carbonat of lime, which had been detached from a group of the same kind of crystals, he observed that a small portion of the crystal was wanting, and that the fracture presented a very smooth surface. Let *h b c d e f g h* (fig. 15.) be the crystal; the fracture lay obliquely as the trapezium *p s u t*, and made an angle of 135°, both with the remainder of the base *a b c s p h* and with *t u e f*, the remainder of the side *i n e f*. Observing that the segment *p s u t i n* thus cut off had for its vertex *i n*, one of the edges of the base *a b c n i h* of the prism, he attempted to detach a similar segment in the part to which the next edge *c n* belonged; employed for that purpose the blade of a knife, directed in the same degree of obliquity as the trapezium *p s u t*, and assisted by the strokes of a hammer. He could not succeed: But upon making the attempt upon the next edge *b c*, he detached another segment, precisely similar to the first, and which had for its vertex the edge *b c*. He could produce no effect on the next edge *a b*; but from the next following, *a h*, he cut a segment similar to the other two. The sixth edge likewise proved refractory. He then went to the other base of the prism *d e f g h r*, and found, that the edges which admitted

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sections similar to the preceding ones were not the edges ef, dr, gk, corresponding with those which had been found divisible at the opposite base, but the intermediate edges de, kr, gf. The trapezium $lqyv$ represents the section of the segment which had kr for its vertex. This section was evidently parallel to the section $psut$; and the other four sections were also parallel two and two. These sections were, without doubt, the natural joinings of the layers of the crystal. And he easily succeeded in making others parallel to them, without its being possible for him to divide the crystal in any other direction. In this manner he detached layer after layer, approaching always nearer and nearer the axis of the prism, till at last the bases disappeared altogether, and the prism was converted into a solid OX (fig. 16.), terminated by twelve pentagons, parallel two and two; of which those at the extremities, that is to say, ASRJO, IGEDO, BAODC at one end, and FKNPQ, MNPXU, ZQPXY at the other, were the results of mechanical division, and had their common vertices O, P situated at the entrance of the bases of the original prism. The six lateral pentagons RSUXY, ZYRIG, &c. were the remains of the six sides of the original prism.

By continuing sections parallel to the former ones, the lateral pentagons diminished in length; and at last the points R, G coinciding with the points Y, Z, the points S, R with the points U, Y, &c. there remained nothing of the lateral pentagons but the triangles YIZ, UXY, &c. (fig. 17.) By continuing the same sections, these triangles at last disappeared, and the prism was converted into the rhomboid ae (fig. 18.)

So unexpected a result induced him to make the same

attempt upon more of these crystals; and he found that all of them could be reduced to similar rhomboids. He found also, that the crystals of other substances could be reduced in the same manner to certain primitive forms; always the same in the same substances, but every substance having its own peculiar form. The primitive form of fluat of lime, for instance, was an octahedron; of sulphat of barytes, a prism with rhomboidal bases; of felspar, an oblique angled parallelopiped, but not rhomboidal; of adamantine spar, a rhomboid, somewhat acute; of blende, a dodecahedron, with rhomboidal sides; and so on.

These primitive forms must depend upon the figure of the integrant particles composing these crystals, and upon the manner in which they combine with each other. Now by continuing the mechanical division of the crystal, by cutting off slices parallel to each of its faces, we must at last reduce it to so small a size that it shall contain only a single integrant particle. Consequently this ultimate figure of the crystal must be the figure of the integrant particles of which it is composed. The mechanical division, indeed, cannot be continued so far, but it may be continued till it can be demonstrated that no subsequent division can alter its figure. Consequently it can be continued till the figure which it assumes is similar to that of its integrant particles.

Integrant particles of three figures.

Hauy has found that the figure of the integrant particles of bodies, as far as experiment has gone, may be reduced to three; namely,

1. The parallelopiped, the simplest of the solids, whose faces are six in number, and parallel two and two.

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2. The triangular prism, the simplest of prisms.

3. The tetrahedron, the simplest of pyramids. Even this small number of primitive forms, if we consider the almost endless diversity of size, proportion, and density, to which particles of different bodies, though they have the same figure, may still be liable, will be found fully sufficient to account for all the differences in cohesion and heterogeneous affinity without having recourse to different absolute forces.

These integrant particles, when they unite to form the primitive crystals, do not always join together in the same way. Sometimes they unite by their faces, and at other times by their edges, leaving considerable vacuities between each. This explains why integrant particles, though they have the same form, may compose primitive crystals of different figures.

Primitive crystalline forms, six.

Mr Hauy has ascertained, that the primitive forms of crystals are six in number; namely,

1. The parallelopiped, which includes the cube, the rhomboid, and all solids terminated by six faces, parallel two and two.

2. The regular tetrahedron.

3. The octahedron with triangular faces.

4. The six-sided prism.

5. The dodecahedron, terminated by rhombs.

6. The dodecahedron, with isosceles triangular faces.

Each of these may be supposed to occur as the primitive form or the nucleus in a variety of bodies; but those only which are regular, as the cube and the octahedron, have hitherto been found in any considerable number.

But bodies, when crystallized, do not always appear in the primitive form; some of them indeed very sel-

dom affect that form; and all of them have a certain latitude and a certain number of forms which they assume occasionally as well as the primitive form. Thus the primitive form of fluat of lime is the octahedron; but that salt is often found crystallized in cubes, in rhomboidal dodecahedrons, and in other forms. All these different forms which a body assumes, the primitive excepted, have been denominated by Hauy *secondary forms*. Now what is the reason of this latitude in crystallizing? why do bodies assume so often these secondary forms?

Secondary crystals owing to

7. To this it may be answered:

Differences in the composition;

1*st*, That these secondary forms are sometimes owing to variations in the ingredients which compose the integrant particles of any particular body. Alum, for instance, crystallizes in octahedrons; but when a quantity of alumina is added, it crystallizes in cubes; and when there is an excess of alumina, it does not crystallize at all. If the proportion of alumina varies between that which produces octahedrons and what produces cubic crystals, the crystals become figures with fourteen sides; six of which are parallel to those of the cube and eight to those of the octahedron; and according as the proportions approach nearer to those which form cubes or octahedrons, the crystals assume more or less of the form of cubes or octahedrons. What is still more, if a cubic crystal of alum be put into a solution that would afford octahedral crystals, it passes into an octahedron: and, on the other hand, an octahedral crystal put into a solution that would afford cubic crystals becomes itself a cube *. Now, how difficult a matter

* Leblanc, *Ann. de Chim.* xiv. 149.

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it is to proportion the different ingredients with absolute exactness must appear evident to all.

In the solvents; and

2*d*, The secondary forms are sometimes owing to the solvent in which the crystals are formed. Thus if common salt be dissolved in water, and then crystallized, it assumes the form of cubes; but when crystallized in urine, it assumes the form not of cubes, but of regular octahedrons. On the other hand, muriat of ammonia, when crystallized in water, assumes the octahedral form, but in urine it crystallizes in cubes *.

3*d*, But even when the solvent is the same, and the proportion of ingredients, as far as can be ascertained, exactly the same, still there are a variety of secondary forms which usually make their appearance. These secondary forms have been happily explained by the theory of crystallization, for which we are indebted to the sagacity of Mr Hauy; a theory which, for its ingenuity, clearness, and importance, must ever rank high, and which must be considered as one of the greatest acquisitions which mineralogy and even chemistry have hitherto attained.

To the different decrements of the crystalline laminæ.

According to this theory, the additional matter which envelopes the primitive nucleus consists of thin slices or layers of particles laid one above another upon the faces of that nucleus, and each layer decreasing in size, in consequence of the abstraction of one or more rows of integrant particles from its edges or angles.

Let us suppose that ABFG (fig. 19.) is a cube composed of 729 small cubes: each of its sides will consist of 81 squares, being the external sides of as many cu-

* Fourcroy and Vauquelin, *Ann. de Chim.* xiv. 149.

bic particles, which together constitute the cube. Upon ABCD, one of the sides of this cube, let us apply a square lamina, composed of cubes equal to those of which the primitive crystal consists, but which has on each side a row of cubes less than the outermost layer of the primitive cube. It will of course be composed of 49 cubes, 7 on each side; so that its lower base *o n f g* (fig. 20.) will fall exactly on the square marked with the same letters in fig. 19.

Above this lamina let us apply a second *l m p u* (fig. 21), composed of 25 cubes; it will be situated exactly above the square marked with the same letters (fig. 19.) Upon this second let us apply a third lamina *v x y z* (fig. 22.), consisting only of 9 cubes; so that its base shall rest upon the letters *v x y z* (fig. 19.) Lastly, on the middle square *r* let us place the small cube *r* (fig. 23.), which will represent the last lamina.

It is evident that by this process a quadrangular pyramid has been formed upon the face ABCD (fig. 19.), the base of which is this face, and the vertex the cube *r* (fig. 23.) By continuing the same operation on the other five sides of the cube, as many similar pyramids will be formed; which will envelope the cube on every side.

It is evident, however, that the sides of these pyramids will not form continued planes, but that, owing to the gradual diminution of the laminæ of the cubes which compose them, these sides will resemble the steps of a stair. We can suppose, however (what must certainly be the case), that the cubes of which the nucleus is formed are exceedingly small, almost imperceptible; that therefore a vast number of laminæ are required to form the pyramids, and consequently that the channels

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which they form are imperceptible. Now DCBE (fig. 24.) being the pyramid resting upon the face ABCD (fig. 19.), and CBOG (fig. 24.) the pyramid applied to the next face BCGH (fig. 19.), if we consider that every thing is uniform from E to O (fig. 24.), in the manner in which the edges of the *laminæ of superposition* (as the Abbé Hauy calls the laminæ which compose the pyramids) mutually project beyond each other, it will readily be conceived that the face CEB of the first pyramid ought to be exactly in the same plane with the face COB of the adjacent pyramid; and that therefore the two faces together will form one rhomb ECOB. But all the sides of the six pyramids amount to 24 triangles similar to CEB; consequently they will form 12 rhombs, and the figure of the whole crystal will be a dodecahedron.

Thus we see that a body which has the cube for the primitive form of its crystals, may have a dodecahedron for its secondary form. The formation of secondary crystals, by the superposition of laminæ gradually decreasing in size, was first pointed out by Bergman. But Hauy has carried the subject much farther: He has not only ascertained all the different ways by which these decrements of the laminæ may take place, but pointed out the method of calculating all the possible variety of secondary forms which can result from a given primitive form; and consequently of ascertaining whether or not any given crystal can be the secondary form of a given species.

The decrements of the laminæ which cover the primitive nucleus in secondary crystals are of four kinds.

These of four kinds.

1. *Decrements on the edges*; that is, on the edges of

the slices which correspond with the edges of the primitive nucleus.

2. *Decrements on the angles;* that is to say, parallel to the diagonals of the faces of the primitive nucleus.

3. *Intermediate decrements*; that is to say, parallel to lines situated obliquely between the diagonals and edges of the faces of the primitive nucleus.

4. *Mixed decrements.* In these the superincumbent slices, instead of having only the thickness of one integrant particle, have the thickness of two or more integrant particles; and the decrement, whether parallel to the edges or angles, consists not of the abstraction of one row of particles, but of two or more. Hauy denotes these decrements by fractions, in which the numerator indicates the number of rows of particles which constitutes the decrement, and the denominator represents the thickness of the laminæ. Thus $\frac{2}{3}$ denotes laminæ of the thickness of three integrant particles, decreasing by two rows of particles.

1. Decrements on edges.

An example of the first law of decrement, or of *decrement on the edges*, has been given above in conversion of the cubic nucleus to a rhomboidal dodecahedron. In that example the decrement consisted of one row of particles, and it took place on all the edges. But these decrements may be more rapid; instead of one, they may consist of two, three, four, or more rows: and instead of taking place on all the edges, they may be confined to one or two of them, while no decrement at all takes place on the others. Each of these different modifications must produce a different secondary crystal. Besides this, the laminæ may cease to be added before they have reached their smallest possible size; the consequence of which must be a different secondary form. Thus, in the example given above, if the superposition

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of laminæ had ceased before the pyramids were completed, the crystal would have consisted of 18 faces, 6 squares parallel to the faces of the primitive nucleus, and 12 hexahedrons parallel to the faces of the secondary dodecahedron. This is the figure of the borat of lime-and-magnesia found at Luneburg.

2. Decrements on the angles.

The second law in which the decrement is on the angles, or parallel to the diagonals of the faces of the primitive nucleus, will be understood from the following example: Let it be proposed to construct around the cube ABGF (fig. 25.), considered as a nucleus, a secondary solid, in which the laminæ of superposition shall decrease on all sides by single rows of cubes, but in a direction parallel to the diagonals. Let ABCD (fig. 26.), the superior base of the nucleus, be divided into 81 squares, representing the faces of the small cubes of which it is composed. Fig. 27. represents the superior surface of the first lamina of superposition; which must be placed above ABCD (fig. 26.) in such a manner, that the points a', b', c' d', (fig. 27.) answer to the points a, b, c, d, (fig. 26.) By this disposition the squares Aa, Bb, Cc, Dd, (fig. 26.) which compose the four outermost rows of squares parallel to the diagonals AC, BD, remain uncovered. It is evident also, that the borders QV, ON, IL, GF, (fig. 27.) project by one range beyond the borders AB, AD, CD, BC, (fig. 26.) which is necessary, that the nucleus may be enveloped towards these edges: For if this were not the case, re-entering angles would be formed towards the parts AB, BC, CD, DA of the crystal; which angles appear to be excluded by the laws which determine the formation of simple crystals, or, which comes to the same thing, no such angles are ever observed in

any crystal. The solid must increase, then, in those parts to which the decrement does not extend. But as this decrement is alone sufficient to determine the form of the secondary crystal, we may set aside all the other variations which intervene only in a subsidiary manner, except when it is wished, as in the present case, to construct artificially a solid representation of a crystal, and to exhibit all the details which relate to its structure.

The superior face of the second lamina will be A'G' L'K' (fig. 28.). It must be placed so that the points a'' b'', c'', a'' correspond to the points, a', b', c', d', (fig. 27.), which will leave uncovered a second row of cubes at each angle, parallel to the diagonals AC and BD. The solid still increases towards the sides. The large faces of the laminæ of superposition, which in fig. 27. were octagons, in fig. 28. arrive at that of a square; and when they pass that term they decrease on all sides; so that the next lamina has for its superior face the square B'M'L'S' (fig. 29.) less by one range in every direction than the preceding lamina (fig. 28). This square must be placed so that the points e', f', g', b', (fig. 29.) correspond to the points e, f, g, b, (fig. 28.) Figures 30, 31, 32, and 33, represent the four laminæ which ought to rise successively above the preceding; the manner of placing them being pointed out by corresponding letters, as was done with respect to the three first laminæ. The last lamina z' (fig. 34) is a single cube, which ought to be placed upon the square z (fig. 33.).

The laminæ of superposition, thus applied upon the side ABCD (fig. 26.), evidently produce four faces, which correspond to the points A, B, C, D, and form

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a pyramid. These faces, having been formed by laminæ, which began by increasing, and afterwards decreased, must be quadrilaterals of the figure represented in fig. 35; in which the inferior angle C is the same point with the angle C of the nucleus (fig. 25. and 26.); and the diagonal LQ represents L'G' of the lamina A'G'L'K' (fig. 28.) And as the number of laminæ composing the triangle LQC (fig. 35.) is much smaller than that of the laminæ forming the triangle ZLQ, it is evident that the latter triangle will have a much greater height than the former.

The surface, then, of the secondary crystal thus produced, must evidently consist of 24 quadrilaterals (for pyramids are raised on the other 5 sides of the primary cube exactly in the same manner, disposed 3 and 3 around each solid angle of the nucleus. But in consequence of the decrement by one range, the three quadrilaterals which belong to each solid angle, as C (fig. 25.), will be in the same plane, and will form an equilateral triangle ZIN (fig. 36.) The 24 quadrilaterals, then, will produce 8 equilateral triangles; and consequently the secondary crystal will be a regular octahedron. This is the structure of the octahedral sulphuret of lead and of muriat of soda.

Third and fourth decrements.

The third law is occasioned by the abstraction of double, triple, &c. particles. Fig. 37. exhibits an instance of the subtractions in question; and it is seen that the moleculæ which compose the range represented by that figure are assorted in such a manner as if of two there were formed only one; so that we need only to conceive the crystal composed of parallelopipedons having their bases equal to the small rectangles $a\ b\ c\ d$,

e d f g, *h g i l*, &c. to reduce this case under that of the common decrements on the angles.

This particular decrement, as well as the fourth law, which requires no farther explanation, is uncommon. Indeed Hauy has only met with mixed decrements in some metallic crystals.

These different laws of decrement account for all the different forms of secondary crystals. But in order to see the vast number of secondary forms which may result from them, it is necessary to attend to the different modifications which result from their acting separately or together. These modifications may be reduced to seven.

Modifications to which these decrements are subject.

1. The decrements take place sometimes on all the edges, or all the angles, at once.

2. Sometimes only on certain edges, or certain angles.

3. Sometimes they are uniform, and consist of one, two, or more rows.

4. Sometimes they vary from one edge to another, or from one angle to another.

5. Sometimes decrements on the edges and angles take place at the same time.

6. Sometimes the same edge or angle is subjected successively to different laws of decrement.

7. Sometimes the secondary crystal has faces parallel to those of the primitive nucleus, from the superposition of laminæ not going beyond a certain extent.

Hence Mr Hauy has divided secondary forms into two kinds, namely, *simple* and *compound*. Simple secondary crystals are those which result from a single law of decrement, and which entirely conceal the primitive nucleus. Compound secondary crystals are those

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which result from several laws of decrement at once, or from a single law which has not reached its limit, and which of course has left in the secondary crystal faces parallel to those of the primitive nucleus.

"If amidst this diversity of laws (observes Mr Hauy), sometimes insulated, sometimes united by combinations more or less complex, the number of the ranges subtracted were itself extremely variable; for example, were these decrements by 12, 20, 30, or 40 ranges, or more, as might absolutely be possible, the multitude of the forms which might exist in each kind of mineral would be immense, and exceed what could be imagined. But the power which affects the subtractions seems to have a very limited action. These subtractions, for the most part, take place by one or two ranges of molecules. I have found none which exceeded four ranges, except in a variety of calcareous spar, forming part of the collection of C. Gillet Laumont, the structure of which depends on a decrement by six ranges; so that if there exist laws which exceed the decrements by four ranges, there is reason to believe that they rarely take place in nature. Yet, notwithstanding these narrow limits by which the laws of crystallization are circumscribed, I have found, by confining myself to two of the simplest laws, that is to say, those which produce subtractions by one or two ranges, that calcareous spar is susceptible of 2044 different forms: a number which exceeds more than 50 times that of the forms already known; and if we admit into the combination decrements by three and four ranges, calculation will give 8,388,604 possible forms in regard to the same substance. This number may be still very much augment-

ed in consequence of decrements either mixed or intermediary.

The striæ remarked on the surface of a multitude of crystals afford a new proof in favour of theory, as they always have directions parallel to the projecting edges of the laminæ of superposition, which mutually go beyond each other, unless they arise from some particular want of regularity. Not that the inequalities resulting from the decrements must be always sensible, supposing the form of the crystals had always that degree of finishing of which it is susceptible; for, on account of the extreme minuteness of the molecules, the surface would appear of a beautiful polish, and the striæ would elude our senses. There are therefore secondary crystals where they are not at all observed, while they are very visible in other crystals of the same nature and form. In the latter case, the action of the causes which produce crystallization not having fully enjoyed all the conditions necessary for perfecting that so delicate operation of nature, there have been starts and interruptions in their progress; so that, the law of continuity not having been exactly observed, there have remained on the surface of the crystal vacancies apparent to our eyes. These small deviations are attended with this advantage, that they point out the direction according to which the striæ are arranged in lines on the perfect forms where they escape our organs, and thus contribute to unfold to us the real mechanism of the structure.

The small vacuities which the edges of the laminæ of superposition leave on the surface of even the most perfect secondary crystals, by their re-entering and salient angles, thus afford a satisfactory solution of the difficul-

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ty a little before mentioned; which is, that the fragments obtained by divison, the external sides of which form part of the faces of the secondary crystal, are not like those drawn from the anterior part. For this diversity, which is only apparent, arises from the sides in question being composed of a multitude of small planes, really inclined to one another, but which, on account of their smallness, present the appearance of one plane; so that if the division could reach its utmost bounds, all these fragments would be resolved into molecules similar to each other, and to those situated towards the centre.

The fecundity of the laws on which the variations of crystalline forms depend, is not confined to the producing of a multitude of very different forms with the same molecules. It often happens also, that molecules of different figures arrange themselves in such a manner as gives rise to like polyhedra in different kinds of minerals. Thus the dodecahedron with rhombuses for its planes, which we obtained by combining cubic molecules, exists in the granite with a structure composed of small tetrahedra, having isosceles triangular faces; and I have found it in sparry fluor (*fluat of lime*), where there is also an assemblage of tetrahedra, but regular: that is to say, the faces of which are equilateral triangles. Nay more, it is possible that similar molecules may produce the same crystalline form by different laws of decrement. In short, calculation has conducted me to another result, which appeared to me still more remarkable, which is, that, in consequence of a simple law of decrement, there may exist a crystal which externally has a perfect resemblance to the nu-

cleus, that is to say, to a solid that does not arise from any law of decrement*."

Such is a general view of Hauy's theory of crystallization, which has led already to several very important discoveries in mineralogy, and may be expected to lead to still more important ones hereafter. The evidence for its truth is the complete manner in which it explains the phenomena, and the exact coincidence of matter of fact in every instance, with the result of calculation. But as it cannot be shewn that the secondary forms are actually crystallized according to the theory, we must consider it in the light of a mathematical hypothesis; an hypothesis, however, of very great importance, because it serves to link together a vast number of otherwise unconnected facts; because it enables us to subject all the forms of crystals to calculation; and because it puts it in our power to ascertain the nature of a body with the utmost certainty, from an accurate examination of the figure of its crystals. Such hypotheses may be considered as the clues which lead us through the otherwise impenetrable mazes of error, and conduct us at last, though after a tedious journey, to the goal of certainty and truth.

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* *Ann. de Chim.* xvii. 225. For a more complete account of this theory, the reader is referred to Hauy's *Mineralogy*, vols 1st and 2d. A larger detail would have been inconsistent with the plan of this Work.

CHAP. III.

OF HETEROGENEOUS AFFINITY

HETEROGENOUS AFFINITY differs from cohesion merely in being confined to heterogeneous particles. It is usually known by the appellation of *chemical affinity*, and has hitherto almost exclusively occupied the attention of chemists, on the supposition that it is exclusively the cause of all the compositions and decompositions with which they are conversant; though in fact its influence is neither more extensive nor more important than that of cohesion. Indeed the two powers are so intimately connected, that their actions are very seldom exhibited separately. In treating of heterogeneous affinity, it is necessary to consider, 1. How heterogeneous particles combine; 2. In what proportions they are capable of combining; 3. The force with which they combine; and, 4. What takes place when a variety of heterogeneous particles are made to act upon each other at the same time. These topics will form the subject of the four following Sections.

SECT. I.

OF COMBINATION.

1. WHETHER there exists a reciprocal affinity between every species of the particles of bodies, is a point which cannot easily be determined, though it is certainly very probable that there does. But as the particles of bodies are usually found cohering together in masses, it is evident that no heterogeneous bodies can combine unless their affinity for each other be stronger than the cohesive force which unites the respective particles of each. Now, whenever two bodies constantly refuse to combine, in whatever situation we place them, we say that they have *no* affinity for each other; meaning merely, that their affinity is not so great as to produce combination. Thus we say that there is no affinity between oil and water, because these two liquids refuse to combine together; yet when oil is united with alkali, and in the state of soap, it dissolves in water; a proof that there does exist an affinity between water and oil, tho' not strong enough to produce combination. We say also, that there is no affinity between azote and lime, because azotic gas cannot be combined with that earth: yet nitric acid dissolves lime readily; which shews us that the refusal of lime and azotic gas to combine is not the consequence of the want of an affinity between these two bodies, but of some other cause.

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Bodies to be combined; either insulated

2. We may present a body to another with which it is capable of combining in two different states; either insulated or already combined with some other body. Thus we may present lime to nitric acid, either in the state of pure lime, or combined with carbonic acid, and consequently in the state of a carbonat.

In the first case the affinity is opposed by the cohesion, and combination does not take place unless that force can be overcome. Hence the reason that combination seldom succeeds well, unless some of the bodies to be combined be fluid, or be assisted by heat, which has the property of diminishing the force of cohesion. Indeed there are not wanting numerous instances of solid bodies combining together without the assistance of heat; but they are always bodies which have the property of becoming liquid in the act of combination. Thus common salt and snow, muriat of lime and snow, &c. combine rapidly when mixed, and are converted into liquids.

It is to the force of cohesion that the difficulty of dissolving the diamond, the sapphyr, and many other natural bodies, is to be ascribed, though composed of ingredients very readily acted on by solvents when their cohesive force is sufficiently diminished. If pure alumina be formed into a paste, and heated sufficiently, it becomes so hard that no acid can act upon it; yet its nature is not in the least changed: by proper trituration it may be again rendered soluble; and when precipitated from this new solution, it has recovered all its original properties. The effect of the fire, then, was merely to increase the cohesion, by separating all the water, and allowing the particles to approach nearer each other.

3. Even when the cohesive force of the particles to be combined is not very great, it may be still sufficient to prevent combination from taking place, provided the other body can only approach it in a very small mass. Hence the reason that carbonic acid gas, and other elastic fluids, have scarcely any action on the greater number of bodies, though they combine with them readily when the force of cohesion presents no opposition. Thus the oxygen of the atmosphere does not combine with sulphur in its natural state, though it unites with it readily when the sulphur is combined with hydrogen and potass, bodies which diminish its cohesion very considerably, or when it is converted into its integrant particles by the action of heat.

Or previously combined;

4. In the second case, or when the body presented to be combined with another is already in combination with some other body, it does not altogether leave the old body and combine with the new, but it is divided between them in proportion to the mass and the affinity of these bodies. Thus when lime, already in combination with phosphoric acid, is presented to sulphuric acid, it does not altogether leave the phosphoric to combine with the sulphuric acid, but it divides itself between these two acids, part combining with the one and part with the other, according to the respective quantities of each of these acids, and the strength of their affinity for the lime. This important point has been lately put in a very clear light by Mr Berthollet. Chemists had formerly in a great measure overlooked the modification produced on the action of heterogeneous bodies on each other by the different proportions of each; supposing that in all cases a substance A, which has a stronger affinity for C than B has, is capable of

And then they are parted between the two acting bodies.

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taking C altogether from B, provided it be added in sufficient quantity, how great soever the proportion of B exceeds that of A. Several exceptions, indeed, had been pointed out to this general law. Thus Cavendish ascertained, that lime-water is incapable of depriving air completely of carbonic acid. But Berthollet has demonstrated, that this pretended law never holds; that no substance whatever is capable of depriving another of the whole of a third, with which it is combined, except in particular circumstances, however strong its affinity for that third may be, and in how great a proportion soever it be added. Thus no proportion of lime whatever is capable of depriving the carbonat of potass of the whole of its acid. Neither does sulphuric acid decompose phosphat of lime completely, nor ammonia sulphat of alumina, nor potass sulphat of magnesia.

In short, it may be considered as a general law in chemistry, that the smaller the proportion of a body in combination with a given quantity of another body is, with the greater energy is it retained; so that at last the force of its affinity becomes stronger than any direct force that can be applied to separate it. Hence the impossibility of depriving sulphuric acid and several other bodies completely of water.

Bodies act in proportion to their mass.

Berthollet has shown also, that every body, how weak soever its affinity for another may be, is capable of abstracting part of that other from a third, how strong soever the affinity of that third is, provided it be applied in sufficient quantity. Thus potass is capable of abstracting part of the acid from sulphat of barytes, from oxalat of lime, phosphat of lime, and carbonat of lime: soda and lime abstract part of the acid from sulphat of potass, and nitric acid abstracts part of the base

from oxalat of lime. Hence it follows that substances are capable of decomposing each other reciprocally, provided they be added respectively in the proper quantity. Indeed this was known formerly to be the case, though it had not been considered as a general law till Berthollet drew the attention of chemists to it. Sulphuric acid decomposes nitrat of potass altogether by the assistance of heat. The nitric acid is driven off, and there remains behind sulphat of potass with an excess of acid. On the other hand, if nitric acid be poured into sulphat of potass in sufficient quantity, it takes a part of the base from the sulphuric acid. In the same manner phosphoric acid decomposes muriat of lead, and muriatic acid on the other hand decomposes phosphat of lead.

This reciprocal decomposition follows as a consequence from the nature of affinity. For if the affinity of one particle for another be an absolute force (supposing the distance, figure, and density constant), it certainly ought to follow that this force must be increased by the number of the attracting particles. If a particle A attract a particle B with a force $= x$, two particles A concurring together ought certainly to attract with a force $= 2x$, or at least with a force $= y > x$. Hence we see that the aggregate force of attraction ought to increase with the aggregate number of particles.

Decomposition explained.

But this increase is not sufficient to explain the cause of decomposition. For undoubtedly, how much soever we suppose the attraction of a body A for another body C, to exceed the attraction of B already in combination with C, the addition of A, in how large a quantity soever, cannot be conceived to destroy the combination of B with C, unless some other cause intervene. The attraction between B and C cannot be annihilated,

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though it may be considerably diminished; it must therefore be sufficient to keep the two bodies still united, notwithstanding the presence of A. A, no doubt, will also combine with C; the consequence of which would be a new compound, into which all the three bodies equally enter. This, indeed, must always hapen when different bodies are mixed together, whatever their affinities for each other may be, unless some force or other intervene to determine the exclusion of some particular bodies. Thus, if the particles A and C, (supposing them numerous) have not only a strong affinity for each other, but also a strong force of cohesion, which leads the combined particles A + C to unite together and to form masses of sensible magnitude, the particles B may be excluded from these masses either totally or partially, according to their nature, while the masses themselves, becoming too heavy to remain suspended in a fluid, precipitate to the bottom. Hence the reason that barytes precipitates sulphuric acid completely from most of its combinations, and that muriatic acid has the same effect upon silver. Again, if the particles B are elastic, the addition of A, by weakening the force by which they are retained, conspires with this elasticity; the consequence of which may be, that B may fly off altogether, and leave A and C in combination. Hence the reason that sulphuric acid separates carbonic acid from all its combinations.

The presence of an elastic body, like carbonic acid, constitutes an exception to the general rule, that, other things being equal, the affinities of bodies are as their masses: for the elastic body making its escape constantly as it is disengaged, cannot possibly act by its mass.

The presence of an absolutely insoluble body, if there be any such, must constitute an exception to both the general rules of Berthollet: For the addition of a body A, which forms an insoluble compound with C, may decompose completely the compound B + C. A and B combining, and forming an insoluble aggregate, must precipitate completely to the bottom. Hence barytes leaves no sensible quantity of sulphuric acid when dropt into a solution containing that acid; and muriatic acid in the same circumstance leaves no sensible quantity of silver. In this case, too, the body A must act independently of its mass; because separating almost instantaneously from the solution, the mass of B, however great, cannot oppose its action.

These remarks are sufficient to give us some notion of the manner in which bodies combine together. Let us now consider the *proportions* in which they are capable of combining.

SECT. II.

OF SATURATION.

The word Saturation, like most other technical terms introduced into chemistry before the science had acquired much precision, has been used with a great deal of latitude, being sometimes taken in one sense and sometimes in another. But in order to be understood, it is necessary to use the word with some degree of precision: for that reason I shall, in this Section, confine it to that particular sense which seems best adapted to it.

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Saturation explained.

1. If we make the attempt, we shall find that water will not dissolve any quantity of salt that we please. At the temperature of 60°, it dissolves only 0.354 parts of its weight of salt; and if more salt than this be added, it remains in the water undissolved. When water has dissolved as much salt as possible, it is said to be *saturated* with salt. This sense is at least analogous to the original meaning of the word, and is that to which I mean to restrict it in this Section. Whenever, then, a substance A refuses to combine with an additional quantity of another body B, we may say that it is saturated with B. The cause of this refusal of the water to dissolve any more salt has been indicated in the preceding Chapter. It takes place whenever the affinity of the water and salt is balanced by the cohesion of the particles of the salt, and therefore indicates that these two forces are equal.

In the same manner water, after having absorbed a certain quantity of carbonic acid gas, refuses to absorb any more. We may indeed pass carbonic acid gas thro' water in this state, but it makes its escape unaltered. Water which refuses to absorb carbonic acid gas is *saturated* with that acid. This saturation takes place when the affinity between the gas and the water is balanced by the elasticity of the gas, and indicates of course that these two forces are equal.

Consists in the balancing of two forces.

In these two instances the saturation is occasioned by opposite causes. The salt refuses to dissolve in the water when the *cohesion* of its particles equals its affinity for the water; the carbonic acid gas, when the *repulsion* of its particles equals its affinity for water. In the first case, it is the attractive force of cohesion which opposes farther solution; in the second case, it is the

repulsive force of elasticity. Hence the different methods which must be followed to diminish these forces, and enable the water to dissolve a greater proportion of these respective bodies. Heat, by diminishing the force of cohesion, enables water to dissolve a greater proportion of saline bodies. Accordingly we find that in most cases hot water dissolves more salt than cold water. Common salt is almost the only exception to this general law. On the other hand, cold, by diminishing the elasticity, or at least the expansibility of gaseous bodies, enables water to dissolve a greater proportion of them. Thus the colder the water is, the greater a proportion of carbonic acid is it capable of dissolving. The freezing point of water limits this increase of solubility, because at that point the cohesive force of the particles of water becomes so great as to cause them to cohere, to the exclusion of those bodies with which they were formerly combined. Hence the reason that most bodies separate from water when it freezes. But they generally retard the freezing considerably, by opposing with all the strength of their affinity the cohesion of the water. The consequence is, that the freezing point of water, when it holds bodies in solution, is lower than the freezing point of pure water. A table of the freezing points of different saline solutions would be a pretty accurate indication of the affinity of the different salts for water: for the affinity of each salt is of course proportional to the degree of cold at which it separates from the water, that is, to the freezing point of the solution.

In this sense of the word *saturation*, which is certainly the only one that it ought to bear, it may be said with propriety that there are certain bodies which can

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not be saturated by others. Thus water is capable of combining with any quantity whatever of sulphuric acid, nitric acid, and alcohol; and all bodies seem capable of combining with almost any quantity whatever of caloric. Several of the metals, too, are capable of combining with any quantity whatever of some other metals. In general, it may be said that those bodies called *solvents* are capable of combining in any quantity with the substances which they hold in solution. Thus water may be added in any quantity, however great, to the acids, and to the greater number of salts.

Neutralization.

2. If we take a given quantity of sulphuric acid diluted with water, and add to it slowly the solution of soda by little at a time, and examine the mixture after every addition, we shall find that for a considerable time it will exhibit the properties of an acid, reddening vegetable blues, and having a taste perceptibly sour: but these acid properties gradually diminish after every addition of the alkaline solution, and at last disappear altogether. If we still continue to add the soda, the mixture gradually acquires alkaline properties, converting vegetable blues to green, and manifesting an urinous taste. These properties become stronger and stronger the greater the quantity of the soda is which is added. Thus it appears that when sulphuric acid and soda are mixed together, the properties either of the one or the other preponderate according to the proportions of each; but that there are certain proportions, according to which, when they are combined, they mutually destroy or disguise the properties of each other, so that neither predominates, or rather so that both disappear.

When substances thus mutually disguise each others properties, they are said to *neutralize* one another.

This property is common to a great number of bodies; but it manifests itself most strongly, and was first observed, in the acids, alkalies, and earths. Hence the salts which are combinations of these different bodies received long ago the name of *neutral salts*. When bodies are combined in the proportion which produces neutralization, they are often said to be *saturated*; but in this case the term is used improperly. It would be much better to confine the word *saturation* to the meaning assigned to it in the beginning of this Section, and to employ the term *neutralization* to denote the state in which the peculiar properties of the component parts mutually disappear; for very frequently neutralization and saturation by no means coincide. Thus in *tartrite of potass* the acid and alkali neutralize each other: yet it cannot be said that the potass is saturated; for it is still capable of combining with more tartarous acid, and of forming supertartrite of potass, a compound in which the ingredients do not neutralize each other; for the salt has manifestly a preponderance of the properties of the acid.

Owing to an equality of affinity.

When two substances neutralize each other, it is not easy to avoid supposing that they are either combined particle to particle, or nearly so. They must at least be combined in such a manner, that the particles of each are distributed everywhere in such equal proportions, that an equal number of both is applied to all bodies in which the compound acts; or rather such a number of each, that its action upon all bodies is exactly equal to the effect of the other. The consequence of this must be, that both of them will act at the same time with equal energy upon every body which is exposed to their action. Hence, as far as their actions are opposite, they

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will mutually destroy each other; and, as far as they are not exactly opposite, they will produce a compound effect different from what would be produced by either singly; just as the mixture of two rays of light produces a colour different from the colour produced by each separatcly.

When bodies neutralize each other, they must be considered as in the most perfect state of combination possible, as they exactly balance each other. Consequently if a body A neutralizes a body B, the two are united in such proportions that the absolute force of the affinity of A for B is equal to that of B for A.

3. A question still remains to be resolved concerning the proportion in which bodies combine, which is attended with very considerable difficulty: Are bodies capable of combining with each other indefinitely, or do they only combine with each other in certain determinate proportions? The observations already made may seem to decide in favour of the first of these suppositions; but let us consider the subject a little more precisely.

Bodies only unite in certain proportions.

Let us suppose two bodies a and b, to have an affinity for each other. Let us take one particle of a and combine it with as many particles of b as can approach within a's sphere of affinity. It is clear that in this case a is absolutely saturated with b, and cannot possibly combine with any more particles of that body. Let us call the new compound $a + x\,b$. If the particles of b have a cohesive force, it is very possible that they may combine indefinitely with the compound $a + x\,b$; but this combination cannot with propriety be considered as the union of more particles of b with a; it would have taken place if a had not been present

at all, and must be ascribed entirely to the cohesion of the particles of *b*. Now if, instead of one particle of *a*, we suppose two or a thousand, the case will remain the same. Each particle may combine with as many particles of *b* as can come within the sphere of its attraction; but all additions of *b* beyond that must be ascribed entirely to the cohesion of the particles of *b*. Thus if *a* remains constant, we see that it can only combine with a finite portion of *b*; consequently in those cases where saturation is impossible, the new doses of the solvent must be considered as combining merely with the solvent, and not with the body held in solution.

There is a maximum and minimum beyond which they cannot pass.

The same observation holds, if we suppose *b* constant and *a* variable. Indeed if we were to consider the reciprocal attractions of the particles of both bodies, and the spheres of attraction which surround every particle, it would be an extremely difficult matter to form any adequate notion of the manner in which they combine and act upon each other. But it is easy to see in general, that if the particles of a body A remain constant, they can only combine with a limited number of particles of another body *b*, because only a limited number can come within the spheres of their attraction.

Thus we see, that, strictly speaking, a given body *a* cannot combine with a body *b* beyond a certain proportion. But is there a limit on the other side? Can *a* combine with any quantity of *b*, however small, provided it be within the maximum? or is it necessary that, before any combination can take place, a certain definite proportion of *b* must be present? What is the minimum of *b* that can combine with a given portion of *a*?

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It is evident that if a has an affinity for b, one particle of each must be capable of combining together; at least nothing can be conceived to hinder them. But this does not answer the question; for we must suppose a considerable number of particles of a present. Let us then make $x\,a$ = number of particles of a, which can approach within the sphere of attraction of a particle of b, and $y\,x\,a$ = quantity of a present; it is evident from what has been said before, that $y\,b$ is the minimum which is capable of combining with $y\,x\,a$. If less be added, part of a will remain combined only by cohesion. If this cohesion does not exist, then it is impossible that a and b can remain in combination in any proportion less than $y\,x\,a$ and $y\,b$. Accordingly in water, where the component parts are elastic fluids, we find them always united in one determinate proportion. In this compound the maximum and minimum coincide apparently: We are not yet far enough advanced in our notions of affinity to say why. And in the metallic oxides, where one of the component parts is an elastic fluid, the minimum as well as the maximum consists of a precise proportion of oxygen.

Thus it appears, that in all combinations there are two precise limits, a minimum and a maximum, beyond which the component parts can never pass. It remains still for us to consider whether they can combine in any proportion within these limits. For instance, if the minimum of oxygen capable of combining with iron be 0.25, and the maximum 0.48, the question to be decided is, Can iron combine with any proportion whatever of oxygen between 0.25 and 0.48? or can it only combine with certain determinate proportions, such as 0.30 or 0.40?

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Whether they combine indefinitely within these limits.

When we consider the matter abstractedly, we can perceive nothing to prevent this combination of bodies in any proportion whatever within the limits of their maxima and minima; though it must be acknowledged that it would be exceedingly difficult to form any adequate notion of the manner in which they are combined in these circumstances. This indefinite combination seems formerly to have been considered as an axiom by chemists. It was abandoned, perhaps with too much facility, in consequence, chiefly, of the experiments of Lavoisier; but the opinion has lately been revived again, and supported with much ingenuity by Berthollet. Let us consult experience, which is alone capable of deciding the point; for our notions of affinity are still too imperfect and confused to warrant any deductions from abstract reasoning.

Now, as far as experience has gone, substances, if we attend only to the proportions in which they combine with each other, may be arranged under four classes.

1. Some seem to combine in any proportion whatever between the maxima and minima.

2. Some combine only in certain determinate proportions between the maxima and minima.

3. Some combine only in the proportions which constitute the maxima and minima.

4. In some the maximum and minimum coincide, so that they are capable of combining only in one determinate proportion. Let us consider each of these classes a little.

The *first* class, strictly speaking, scarcely includes any bodies except those which are incapable of saturation, and which therefore have a minimum but no vi-

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To the *second* class belong almost all combinations of oxygen with other bodies. Thus all the simple combustibles except hydrogen are always found combined with oxygen in certain determinate proportions, and can only be combined artificially in these proportions. Thus we have,

1. Sulphur . . .	Oxide of sulphur, Sulphurous acid, Sulphuric acid.
2. Phosphorus	Oxide of phosphorus, Phosphorous acid, Phosphoric acid.
3. Carbon . . .	Charcoal, Oxide of carbon, Carbonic acid.
4. Azote	Air, Oxide of azote, Nitrous gas, Nitric acid.

With respect to the metallic oxides, our knowledge is not sufficiently precise to be able to decide with confidence. Several of them, as those of lead, seem to belong to the first class; but others, as those of mercury, belong pretty evidently to the second.

To the *third* class belong several of the metallic ox-

ides, which have been examined with the greatest precision, as those of iron, tin, copper, arsenic. In some of them, the capacity of only combining in the maximum and minimum proportion is exceedingly well marked. Thus the red oxide of iron is converted by heat and by sulphureted hydrogen gas to the black oxide: if the black oxide of copper and metallic copper be mixed together in equal quantities in muriatic acid, the oxygen does not divide itself among the whole of the copper; such a portion of the metal only is oxidized as with the oxygen is capable of forming orange oxide, and the rest of the copper remains unaltered. If copper-filings be confined with muriatic acid in a phial half full and close corked, the acid at first acquires a deep green colour, and of course has combined with a portion of the copper, which must previously have been converted into black oxide; but in a few days it becomes quite colourless. The black oxide is gradually decomposed, more copper is dissolved, and acid is found combined, not with the black but with the orange oxide. Here the process stops, unless we uncork the phial for a few minutes. If that be done, the solution becomes again green, and gradually loses its colour as before. If the phial be opened under water, a quantity of that liquid rushes in; a plain proof that part of the air of the phial has disappeared: and if we examine that air, we find it deprived altogether of its oxygen. The nature of the process then is evident: the copper is supplied with oxygen from the air in the vessel. It at first combines with it in that proportion only which constitutes black oxide; afterwards this black oxide, or rather oxymuriat, combines with the precise portion of copper necessary to convert it to orange oxide or mu-

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riat. If air be again presented, the muriat combines with the precise proportion of oxygen which is necessary to convert it into muriat, and so on.

To the *fourth* class belongs *water*, which cannot by any method known be combined in any other proportion than 0.85 oxygen and 0.15 hydrogen. *Ammonia* also belongs to the same class, for it is equally constant in its proportions. It is remarkable that both the component parts of these two bodies are elastic fluids. This elasticity is doubtless the cause of the constancy of the proportions; for it is obvious that there can be only one proportion capable of holding the elasticity of the two component parts in due balance; and if the elasticity of either prevail, the combination cannot take place at all. Substances which are absolutely insoluble, or nearly so, when combined in certain proportions, may also be considered as belonging to the same class, unless the addition of either of the ingredients renders them soluble. Hence the reason of the constancy of the proportions of sulphat of barytes, oxalat of lime, phosphat of lime, fluat of lime, &c.

All compounds belonging to the second and third class have an elastic fluid for one of their ingredients, and those of the third class only manifest their peculiar constitution when they are in combination with some other substance. These observations are sufficient to show that the refusal of bodies to combine, except in their maximum or minimum proportion, or in certain determinate proportions between these two, is owing always, not to the nature of affinity, but to certain peculiarities in their constitution; and that when these peculiarities are not present, these determinate proportions are not observed. But this peculiarity of constitution deserves the highest attention, as we are indebt-

ed to it for that constancy which we find in almost all combinations, and for the permanency of natural bodies in the state in which they have originally combined. Chap. III.

Having thus examined the proportions in which bodies are capable of combining, let us now consider the varieties in the *force* with which they combine, and the attempts which have been made to measure these varieties.

SECT. III.

OF THE STRENGTH OF AFFINITY.

Importance of the subject.

SINCE the affinity of almost every two bodies for each other differs *in strength* from that between every other two, it becomes an important problem *to determine the strength of every affinity in numbers.* The solution of this problem would give a clearness and precision to chemistry equal to that of any other branch of natural philosophy whatever, and enable it to advance with a degree of rapidity hitherto thought unattainable. No wonder, then, that this problem has occupied the attention of some of the most eminent philosophers who have dedicated their time to chemistry. Let us consider the different attempts which have been made to resolve it, that we may see whether any of them will answer the end proposed.

Solution proposed by Wenzel.

Wenzel supposed that the time taken by one body to dissolve another is a measure of the affinity which

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subsists between them. But the hypothesis of that ingenious philosopher will not bear the test of examination; for the *time* of solution evidently depends upon circumstances unconnected with affinity. The cohesion of the body to be dissolved, and the nature of the compound formed, must occasion very great differences in the time of solution of different bodies, even on the supposition that their affinities were all the same.

By Fourcroy,

Fourcroy proposed to measure the affinity of bodies by the difficulty of separating them after they are combined: but we have no method of measuring this difficulty. Lavoisier and De la Place, indeed, proposed *caloric* for this purpose; but there are many compounds which caloric cannot separate, and it never produces a separation except by means of its affinity for one or other of the ingredients of the compound. Before caloric, therefore, could be employed as a measure, it would be necessary to know exactly the strength of its own affinity for every other substance; which is just a case of the problem to be resolved.

By Macquer,

Macquer supposed that the affinity of bodies for one another was in the compound ratio of the facility of their union, and the difficulty of their separation. But as we are in possession of no method of ascertaining either of these, it is evident that this theory, even allowing it to be just (which it certainly is not), could be of no use for assisting us to calculate the force of affinities.

By Morveau.

Another method has been proposed by the distinguished philosophical chemist Mr de Morveau*.

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* Now Mr Guyton. We have used the old name all along in the text to avoid ambiguity.

In 1713, Dr Brook Taylor made some experiments on the adhesion of surfaces; and concluded from them, that the force of adhesion might be determined by the weight necessary to produce a separation. But in 1772, Messrs La Grange and Cigna, observing that the surfaces of water and oil adhere together, and taking it for granted that these two liquids *repel* each other, concluded, in consequence, that their adhesion was not owing to *attraction*; and hence inferred, that *adhesion*, in general, is always owing to the pressure of the atmosphere. This conclusion induced Morveau to examine the subject: he found, that adhesion was *not affected* by the pressure of the atmosphere; for it required the same weight to separate a disk of glass (30 lines in diameter) from the surface of mercury in the open air, and under an exhausted receiver. He observed that the same disk adhered to water with a force of 258 grains, and to the solution of potass, though denser, only with a force of 210. This result not only proved that adhesion was owing to attraction, but made him conceive the possibility of applying this method to the calculation of affinities: For the force of adhesion being necessarily proportional to the points of contact, and this being the case also with affinity, it is evident that the adhesion and the affinity between the same substances are proportional, and that therefore the knowledge of the one would furnish us with the ratio of the other.

Struck with this idea, he constructed cylinders of different metals, perfectly round, an inch in diameter and the same in thickness, and having a small ring in their upper surface, by which they might be hung exactly in equilibrium. He suspended these cylinders, one after another, to the beam of a balance; and after counter-

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poising them exactly, applied them to a quantity of mercury placed about two lines below them, making them slide along its surface, to prevent any air from lodging between them and the mercury. He then marked exactly the weight necessary to overcome their adhesion, taking care to change the mercury after every experiment. The TABLE of the results is as follows:

Gold adheres to mercury with a force of	446 gr.
Silver	429
Tin	418
Lead	397
Bismuth	372
Platinum	282*
Zinc	204
Copper	142
Antimony	126
Iron	115
Cobalt	8

The differences of these results cannot be owing to the pressure of the air, which was the same in all; nor do they correspond to the densities of the metals; nor can they be owing to accidental differences in the polish of the cylinders; for a plate of rough iron adheres more strongly to mercury than one of the same diameter exquisitely polished; but they follow precisely the order of affinity, and therefore may be considered as the measure of the strength of the affinity between these different metals and mercury. They furnish us also with a convincing proof that *affinity* is *attraction*, and

* Morveau, *Ann. de Chim.* XXV. 10.

the same species of attraction with *adhesion*; and that therefore, if the one be reducible to *gravitation*, so must the other.

Mr Achard, convinced of the importance of Mr Morveau's observations, made a great many experiments on *adhesion*, and published the result of them in 1780. He proved that the force of adhesion is not affected by alterations in the height of the barometer, but that its force becomes weaker as the heat of the fluid increased *; and that the temperature remaining the same, the force of adhesion increases in the same ratio with the surfaces of the adhering bodies. He made about 600 experiments on the adhesion of different solids and fluids; proved that the force of adhesion did not depend on the densities of the adhering bodies, nor on the different cohesive force of the fluids; and, after a laborious calculation, concluded, that it depended on the figure of the particles of the adhering fluid and solid.

This method of measuring the force of affinities seems to be an accurate one; and if it could be applied to every case of affinity, would, in all probability, enable us to solve the problem which we are now considering: But unfortunately its application is very limited, being confined to those cases alone in which one of the bodies can be presented in a fluid and the other in a solid state. Nor can it be applied indiscriminately to all those cases; for whenever the cohesion of any liquid is much inferior to the force of its adhesion to any solid, the separation takes place in the particles of the liquid itself,

* Strictly speaking, this is owing not so much to a decrease of the force of adhesion, as that of the cohesion of the fluid itself.

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and consequently we do not obtain the measure of its adhesion to the solid, but of its own cohesion, and that too imperfectly. Thus, for instance, Mr Achard found, that sealing wax adhered to water with a force of 92 grains, and to alcohol only with a force of 53$\frac{1}{4}$ths; yet we know that sealing-wax has a greater affinity for alcohol than for water: because alcohol dissolves it, which water is incapable of doing. The difference in the result in this instance was evidently owing to the smaller cohesion of alcohol. Mr Morveau's method must therefore be confined to those cases in which the cohesion of the liquid is stronger than its adhesion to the solid, which may be known by the surface of the solid not being moistened, and to those in which the cohesion is not much inferior to the adhesion; for then it is evident that the force of cohesion will be increased as the force of adhesion. Let us suppose, for instance, that two solids, A and B, are made to adhere to the surface of a liquid, and that A can only form an adhesion with 50 particles of the liquid, whilst B adheres to 100; it is evident that a much smaller force will destroy the cohesion of the 50 particles to which A adheres with the rest of the liquid, than what will be required to destroy the cohesion of the 100 particles united to B with the same liquid *.

The method of Mr Morveau, then, may be applied with accuracy in both cases; and *when* they occur can only be determined by experiment. It cannot, however, be applied indiscriminately even then; for unless the solid and the fluid be presented in such a state that

* Morveau, *Encyc. Method. Chim.* art. *Adhesion.*

no gas is extricated when the adhesion takes place, an accurate judgment cannot be formed of the force of adhesion. When marble (carbonat of lime), for instance, is applied to the surface of sulphuric acid, there is an extrication of gas, which very soon destroys the adhesion, and prevents an accurate result. Were it possible to employ quicklime instead of marble, this would be prevented; or if this cannot be accomplished, why might not lime be employed, united with some acid that would not assume a gaseous form, and at the same time has a weaker affinity than sulphuric acid for lime? Why might not the phosphat of lime, for instance, be used, which may be reduced to a state of hardness sufficiently great for the purpose? The extrication of gas, during the application of metals to the surfaces of acids, might be prevented by oxidizing their surfaces. It is true, indeed, this could not be done with all the metals, on account of the nature of the oxide, but it might with several; copper, for instance, and silver. It cannot be doubted, that by these methods, and other contrivances that might be fallen upon, a sufficient number of results might be obtained to render this method of the greatest importance. It is rather surprising, therefore, that it has never been prosecuted.

By Kirwan.

Mr Kirwan has proposed another method of solving the problem. While he was engaged in his experiments on the strength of acids, he observed that the quantity of real acid necessary to saturate a given quantity of each of the bases was inversely as the affinity between the respective bases and the acid; and that the quantity of each of the bases necessary to saturate a given quantity of acid was directly as the affinity between the base and the acid. Thus 100 grains of each of the

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acids require more alkali for saturation than lime, and more lime than magnesia, as may be seen in the following TABLE:

100 Grains of	Potass.	Soda.	Lime.	Amm.	Mag.	Alum.
Sulphuric acid	215	165	110	90	80	75
Nitric acid	215	165	96	87	75	65
Muriatic acid	215	158	89	79	71	55

He concluded, therefore, that the affinity between acids and their bases may be estimated by the quantity of bases necessary for saturation. Thus the affinity between potass and sulphuric acid is 215, and that between nitric acid and lime 96*.

Bergman long ago established as a principle, under the name of a chemical paradox, that *the stronger any salt was, the less of any other it required for saturation*. Thus, according to him,

100 parts of potass require 78.5 Sulphuric acid
64 Nitric
51.5 Muriatic
42 Carbonic

100 parts of soda . . . . 177 Sulphuric
135.5 Nitric
125 Muriatic
80 Carbonic

This proposition, which has been admirably illustrated by Morveau†, evidently resolves itself into the two following:

1. A *base* requires *the more* of an acid for saturation *the stronger* its affinity for that acid is.

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* *Phil. Trans.* 1783.

† *Encyc. Method. Chim.* i. 597.

2. An acid requires *the more* of any base for saturation *the greater affinity* it has for that base. Chap. III.

This axiom of Bergman coincides exactly with the observations of Mr Kirwan; but as it is merely empyrical, and as it is often contradicted by the latest experiments on the analysis of salts published by Kirwan, it will be necessary to suspend our judgment till these analytical methods are brought to such a degree of perfection as to decide the point.

By Berthollet. Berthollet has lately proposed another method of estimating the strength of affinity, founded on the principles which he himself first developed. This method gives results which deviate if possible still more widely from the received order of affinities than the axiom of Bergman and Kirwan; but as he has given sufficient reasons to convince us that the received order of affinities is often erroneous, it will be worth while to take a view of his method, in order to discover what new light it will give us to develope the still unknown laws of the variations of affinity.

As the affinities of bodies vary with their mass, it is obvious that, when we consider the affinities of bodies, we must suppose them always acting in certain determinate proportions. Now it has been observed formerly, that there are certain proportions in which bodies neutralize each other; and there is reason to believe that in these proportions the affinity exerted by each of the component parts is precisely of the same force. Now if we suppose that the affinity of a given mass of a given body is a constant quantity, which is at least highly probable; if we suppose farther, that the affinity of a body is the sum of the attractions of all its particles, and consequently that when various bodies of

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different masses exert the same affinity, the absolute affinity of each body is inversely as its mass—we have a method of ascertaining the proportional affinities of various bodies for a body A: for the affinity of each body must be inversely as the mass of each body capable of neutralizing a given quantity of A. Let it be supposed required to find the proportional affinity of the three bodies *b*, *c*, and *d* for A. If to neutralize a given weight of A = 1, there be required of

b a weight = 1
c . . . . . = 2
d . . . . . = 3

Then the affinities of *b*, *c*, and *d* for A are respectively as the inverse of the numbers 1, 2, and 3.

Affinity of *b* = 1 or 6
c = $\frac{1}{2}$ or 3
d = $\frac{1}{3}$ or 2

Such is the method pointed out by Berthollet, or at least the method which follows as a consequence from his observations. Let us compare it with the late experiments of Kirwan, which may be considered as the most accurate determinations of the proportions of acid and alkali which neutralize each other. These TABLES are the following:

Mr Kirwan's Table *of the Composition of Salts.*

Salts.	Component Parts. Basis.	Acid.	Water.	State.
Carbonat of potass . .	41.	43.	16.	Crystallized
Pearl ash	60.	30.	6.	Dry
Carbonat of soda . . .	21.58	14.42	64.	Fully crystallized
ditto . . .	59.86	40.05		Desiccated
barytes . .	78.	22.		Natural or ignited
strontian .	69.5	30.		Natural or ignited
lime . . .	55.	45.		Natural if pure, or artificial ignited
magnesia .	25.	50.	25.	Crystallized
common do.	45.	34.	21.	Dried at 80°
Sulphat of potass . . .	54.8	45.2		Dry
soda	18.48	23.52	58.	Fully crystallized
ditto . . .	44.	56.		Desiccated at 700°
ammonia .	14.24	54.66	31.1	
barytes . .	66.66	33.33		Natural and pure, artificial ignited
strontian .	58.	42.		Natural and pure, artificial ignited
lime	32.	46.	22.	Dried at 66°
ditto . . .	35.23	50.39	14.38	Dried at 170°
ditto . . .	38.81	55.84	5.35	Ignited
ditto . . .	41.	59.		Incandescent
magnesia .	17.	29.35	53.65	Fully crystallized
ditto . . .	36.68	63.32		Desiccated
Alum	12. ignited	17.66	51. of crystal. + 19.24 in the earth	Crystallized
Ditto	63.75	36.25		Desiccated at 700°

TABLE *of the Composition of Salts, continued.*

Salts.	Component Parts. Basis.	Acid.	Water.	State.
Nitrat of potass . . .	51.8	44.	4.2 of Composition	Dried at 70°
soda	40.58	53.21	6.21 of Composition	Dried at 400°
ditto	42.34	57.55	. . . . .	Ignited
ammonia . .	23.	57.	20.	
barytes . . .	57.	32.	11.	Crystallized
strontian . .	36.21	31.07	32.72	Crystallized
lime	32.	57.44	10.56.	Well dried, that is, in Air
magnesia . .	22.	46.	22.	Crystallized
Muriat of potass . . .	64.	36.	. . . . .	Dried at 80°
soda	53.	47. aqueous, 38.88 real	. . . . .	Dried at 80°
ammonia . .		. . . . .	. . . . .	Crystallized
ditto	25.	42.75	32.25	Sublimed
barytes . . .	64.	20.	16.	Crystallized
ditto	76.2	23.8	. . . . .	Desiccated
strontian . .	40.	18.	42.	Crystallized
ditto	69.	31.	. . . . .	Desiccated
lime	50.	42.	8.	Red hot
magnesia . .	31.07	34.59	34.34	Sensibly dry

They give us the affinities of the different bases for sulphuric, nitric, muriatic, and carbonic acids, in the following order and intensity.

Tables of real affinity.

I. SULPHURIC ACID.

	Intensity.
Ammonia	383
Magnesia	171
Lime	143
Soda	127
Potass	82
Strontian	72
Barytes	50

III. MURIATIC ACID.

	Intensity.
Ammonia	171
Magnesia	111
Lime	84
Soda	73
Potass	56
Strontian	46
Barytes	31

II. NITRIC ACID.

	Intensity.
Ammonia	245
Magnesia	209
Lime	179
Soda	136
Potass	85
Strontian	85
Barytes	56

IV. CARBONIC ACID.

	Intensity.
Ammonia	
Magnesia	200
Lime	81
Soda	66
Potass	105
Strontian	43
Barytes	28

The order and intensity of these four acids for the same bases may be seen from the following TABLE:

Acids.	Potass.	Soda.	Anum.	Baryt.	Stront.	Lime.	Magn.
Muriatic	177	136	58	314	216	118	80
Sulphuric	121	78	26	200	131	69	57
Nitric	117	73	40	178	116	50	47
Carbonic	95	149		35	231	122	50

In these Tables we see that the affinities follow the same order, except in the case of carbonic acid, from

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the nature of which it is not so easy to determine in what proportion it combines with the various bases as it is to determine the same thing with regard to the other acids.

In the first set of Tables, we see that the bases follow precisely the inverse order of what is commonly supposed to be their affinities, and which have been given from Bergman in the preceding part of this Work. Ammonia has the strongest affinity for the acids, and barytes the weakest. This is contrary to the order in which these substances decompose, or rather precipitate each other. Consequently if it be the real order of the affinities of the bases for the acids, decomposition must be determined by something else than the force of affinity.

Why the order of affinity and of decomposition may be different.

If we consider the matter with attention, it will not be difficult to see the reason why the order of affinity and of decomposition is different: Ammonia is an elastic fluid, of course it makes its escape as soon as it is disengaged; and its elasticity conspires to render its disengagement more easy. Hence any substance, how weak soever its affinity is, may be capable of disengaging it from its combination, provided it be added in sufficient quantity, and the decomposition be assisted by heat. The disengagement of ammonia then by the other bases is no sufficient proof that its affinity is inferior to them

Magnesia forms with sulphuric acid a very soluble compound; hence the reason that sulphuric acid is separated from it by barytes, strontian, lime, and potass. These bodies form salts scarcely soluble; and therefore the attraction of cohesion enables them to abstract the acid, notwithstanding the inferiority of their affinity.

Magnesia, too, has a strong tendency to cohere together in visible masses. This cohesive tendency is sufficient to enable soda to displace it from sulphuric acid.

This tendency to cohesion may be the reason why lime is precipitated from its solution in acids in several instances by potass and soda. The superiority of potass over soda has been determined merely on account of the greater insolubility of most of the salts of potass. The same thing has occasioned the supposed superiority of barytes over strontian.

But it would be tedious to examine all the different salts particularly. The causes of their decomposition, even on the supposition that their real affinities are as in the above Tables, will easily suggest themselves, at least after the perusal of the next Section.

With respect to the affinity of the acids for the respective bases, they follow the order which has long been recognized in the metallic salts; muriatic acid first, then the sulphuric, and the nitric in the third place. The carbonic acid ought not to be taken into consideration, because the composition of the salts, into which it enters, must still be considered as very imperfectly determined. The reason why muriatic acid has been supposed to have a weaker affinity for the alkalies and earths than sulphuric acid is, that its salts are much more soluble than those into which sulphuric acid enters.

Upon the whole, then, we may consider it as exceedingly probable that the real order of affinities does not deviate far from that given in the above Tables. The method pointed out by Berthollet, for determining the strength of affinities, therefore, will probably lead to consequences of the greatest importance. It will oblige

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chemists to attend more closely to the reciprocal action of bodies on each other, and the result must be the discovery of several general laws, which will greatly facilitate the acquisition and the advancement of the science. Even already some of these have been laid open by Berthollet, as we shall see in the next Section.

SECT. IV.

OF COMPOUND AFFINITY.

ALTHOUGH every chemical combination is produced by the same general law, yet as their phenomena vary somewhat according to circumstances, affinities have, for the sake of greater perspicuity, been divided into classes. These classes may be reduced to two, namely, *simple* affinity and *compound* affinity.

Simple affinity.

The *first class* comprehends all those cases in which only *two bodies combine* together; as, for instance, sulphuric acid and potass, oxygen and carbon. The affinities which belong to this class are known by the name of *simple* or *single affinities*. Although one of the substances to be combined happens to be already united with another body, the combination is still reckoned a case of single affinity. Thus suppose the sulphuric acid previously combined with magnesia, and forming with it the salt called *sulphat of magnesia*, as soon as potass is presented, the acid leaves the earth (which is precipitated) and unites with the alkali. Even when three bodies combine, it often happens that the union is

produced merely by single affinity. Thus, when some potass is dropped into tartarous acid, part of the acid unites with the alkali, and forms tartrite of potass; after this the remainder of the acid combines with the tartrite just formed, and composes a new salt known by the name of *supertartrite of potass* or *tartar*. This is evidently nothing else than two instances of simple affinity immediately following each other.

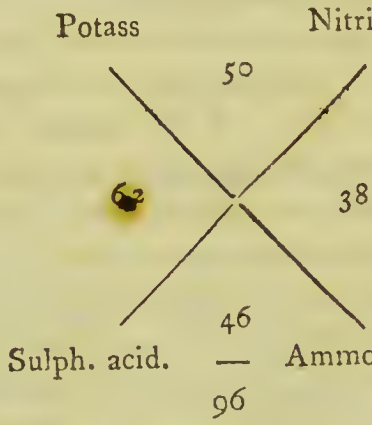
Compound affinity.

When more than three bodies are mixed, decompositions and new combinations often take place, which would not have been produced had the bodies been presented in a separate state. If, for instance, into a solution of sulphat of ammonia there be poured nitric acid, no decomposition is produced, because the sulphuric acid has a stronger affinity for ammonia than nitric acid has. But if nitrat of potass be poured in, we obtain by evaporation two new bodies, *sulphat of potass*, and *nitrat of ammonia*. Such cases of decomposition form the *second class of affinities*. They were called by Bergman cases of *double elective attraction;* a name which is exceedingly proper when there are only four bodies concerned. But as there are often more than four, it is necessary, as Mr Morveau observed, to employ some more comprehensive term. The phrase *compound affinity* may be employed with propriety, comprehending under the term all cases where more than three bodies are present, and produce combinations which would not have been formed without their united action. In these cases the affinity of all the various bodies for each other acts; and the resulting combination has been supposed to be produced by the action of those affinities which are strongest.

The manner in which these combinations and de-

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compositions take place, was thus explained by Dr Black. Let the affinity between potass and sulphuric acid be = 62; that between nitric acid and ammonia = 38; that between the same acid and potass = 50; and that between the sulphuric acid and ammonia = 46. Now, let us suppose that all these forces are placed so as to draw the ends of two cylinders crossing one another, and fixed in the middle in this manner,



(100

96

It is evident, that as 62 and 38 = 100 are greater than 50 + 46 = 96, they would overcome the other forces and shut the cylinders. Just so the affinity between ammonia and nitric acid, together with that between sulphuric acid and potass, overcomes the affinity between ammonia and sulphuric acid, and that between nitric acid and potass, and produces new combinations.

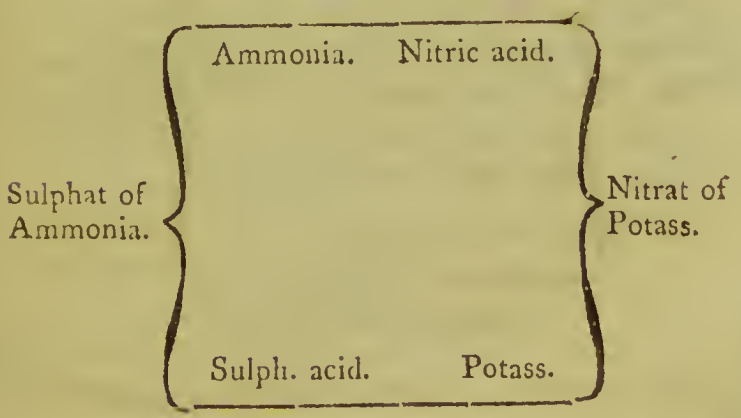
It has been supposed that in all cases of compound affinity, there are two kinds of affinities to be considered; 1*st*, Those affinities which tend to preserve the old compound, these Mr Kirwan has called *quiescent* affinities; and those which tend to destroy them, which he has called *divellent* affinities.

Thus, in the instance above given, the affinity be-

tween ammonia and sulphuric acid, and that between nitric acid and potass, are quiescent affinities, which endeavour to preserve the old compound; and if they are strongest, it is evident that no new compound can take place. On the contrary, the affinity between potass and sulphuric acid, and that between nitric acid and ammonia are divellent affinities; and as they are in this case strongest, they actually destroy the former combinations and form new ones.

Bergman, who published a great many cases of compound affinities, employed to explain them a method somewhat different from this. He would have represented the above case in the following manner:

Nitrat of Ammonia.



Sulphat of Potass.

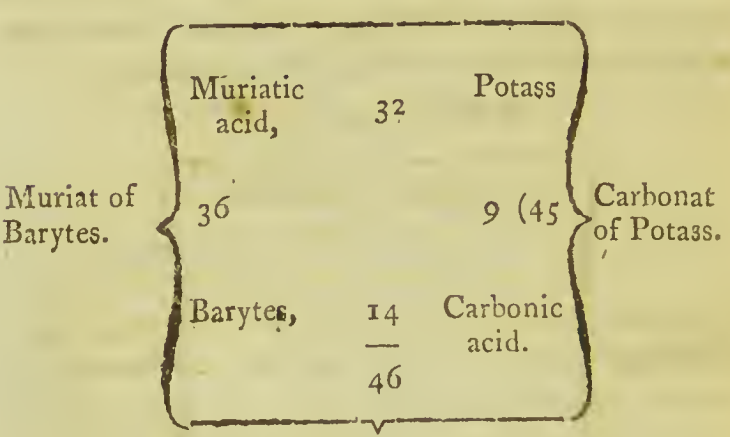
At the four corners of an imaginary square are placed the four substances, so that one acid shall be diagonally opposite to another. On the right and left side of the square are placed the old compounds, each on the side of its own ingredients, and above and below are placed the new compounds.

Mr Elliot improved this method of Bergman, by adding numbers expressive of the affinity of the various

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substances. These numbers were merely arbitrary, but chosen so as to answer all known cases of decomposition. Thus it was known that muriat of barytes and carbonat of potass mutually decompose each other. Therefore supposing that the affinity between the muriatic and barytes = 36; that between the same acid and potass = 32; the affinity between potass and carbonic acid = 9; and that between the same acid and barytes = 14;—we have the following formula of their decomposition:

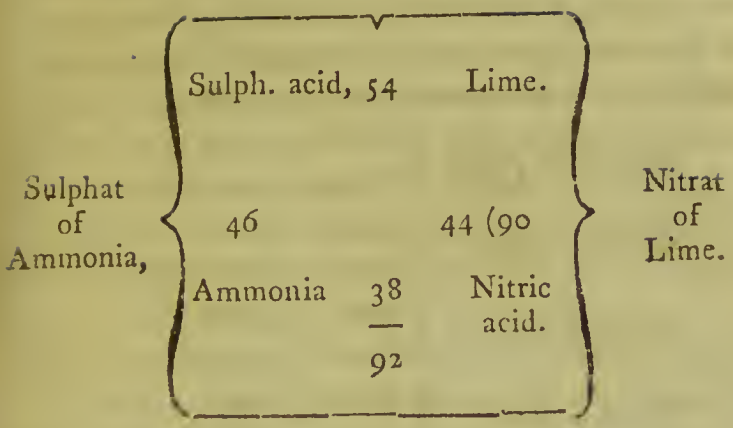
Muriat of Potass.



Carbonat of Barytes.

Another instance of decomposition by compound affinities

Sulphat of Lime.



Nitrat of Ammonia.

Such were the opinions concerning compound affinity which had been received by all philosophers, in consequence, chiefly, of the dissertation published on the subject by Bergman. But the late experiments of Berthollet have demonstrated, that these opinions were in many respects erroneous, and that chemists had too carlessly admitted the existence of these complete decompositions without sufficient examination.

Action of salts depends on their proportions.

1. It has been supposed that when two of those salts which mutually decompose each other are mixed together, the decomposition instantly takes place in consequence of the force of affinities alone, independent of the proportions of the ingredients. Thus when *sulphat of potass* and *nitrat of lime* are mixed together, it was supposed that the sulphuric acid, if present in sufficient quantity, combines with the whole of the lime and disengages the nitric acid and the potass, which also combine till the least abundant of the two be saturated. But if this were the case, some of the four ingredients must be left disengaged, as the proportions of the in-

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gredients of the salts formed by the four ingredients are not such as to saturate each other. According to Mr Kirwan's experiments, the proportions of acid and alkali in the four following salts are as under :

Sulphat of potass	Acid	100
	Potass	121.48
Sulphat of lime	Acid	100
	Lime	70
Nitrat of potass	Acid	100
	Potass	117.7
Nitrat of lime	Acid	100
	Lime	55.7

Now let sulphat of potass and nitrat of lime be mixed together ; let the quantity of sulphat of potass be such, that the acid contained in it amounts to 100 ; and let a more than sufficient quantity of nitrat of lime be added, to saturate the sulphuric acid with lime. It is evident that for that purpose 70 of lime must be present ; and the quantity of nitric acid combined with these 70 must be 123.8. This quantity would require for saturation 145.7 of potass, but there are only 121.48 in the mixture ; consequently there ought to exist in the mixture, after the mutual decomposition of the salts, a quantity of nitric acid in a state of liberty. But the fact is, that no such excess of acid exists in the mixture *. This is a sufficient proof that the decomposition does not take place in the manner that has been supposed. It may be said, indeed, that the composition of these salts may not be sufficiently known to warrant reasoning from it. But be the proportion of the ingredients what it may,

* *Ann. de Chim.* xxv. 295.

still if the decomposition were absolute, as has been supposed, when mixed in any proportion whatever, except in one, some of the ingredients ought to remain disengaged; but as this does not happen either in this case or in any other, we have a right to conclude that the decomposition is not what it has been considered.

2. When two saline solutions are mixed together, either no apparent change takes place, or a precipitate is formed. Let us consider each of these cases.

When no precipitate takes place they combine.

When no precipitation takes place, the two salts no doubt combine together, and form a compound consisting of the two acids and their bases; and the degree of saturation must be the same as before mixture, because the proportions and the affinities must continue the same. Hence the reason that in these cases there are never any indications of any one of the ingredients being disengaged from the others. Hence also the reason that when two salts are dissolved in water, they encrease the solubility of each other. Their mutual affinity serving as an additional counterbalance to the cohesion of each. Thus Vauquelin has shewn that saturated solutions of sulphat of lime, alum, and sulphat of potass, are capable of dissolving a greater proportion of common salt than pure water is *.

The precipitate consists of the least soluble salts.

3. When two salts may be mixed together without any precipitation taking place, it is a proof that all the salts capable of being formed by the component parts of each are soluble. Hence the alkaline salts very rarely occasion a precipitate when mixed together, nor the earthy salts when the acid combined in each is such as to form soluble salts with all the earthy bases, as nitric

* *Ann. de Chim* xiii. 89.

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acid, muriatic acid. On the other hand, when a precipitate takes place, some two of the ingredients form an insoluble compound; consequently we can easily determine before-hand whether or not a precipitate will take place. It is from this precipitation chiefly that double decompositions have been determined. It is obvious that they are occasioned not by the superiority of the affinity of the ingredients which precipitate, but by the strong tendency which these ingredients have to cohere together. The consequence of which tendency is the exclusion of the other component parts, and the precipitation of the masses as they form. It may be considered, then, as a general law, that "whenever a salt is insoluble, the two ingredients which compose it, whenever they meet in a solution, precipitate in combination." For this general law we are indebted to Mr Berthollet.

Thus barytes forms an insoluble compound with sulphuric acid, phosphoric acid, oxalic acid, tartarous acid, &c. Consequently when a salt, whose base is that earth, is mixed with a salt containing any of these acids, a precipitation takes place consisting of the barytes combined with the acid. *Salts of lime* form a precipitate with oxalats, tartrites, citrats, phosphats, fluats, and sometimes with sulphats. The alkaline carbonats occasion a precipitate in all the earthy salts, because all the earthy carbonats are insoluble. Acetite of lead occasions a precipitate in sulphats, muriats, phosphats, mucitates, &c. Nitrat of silver in the muriats. But it would be endless to run over all the precipitates occasioned by the mixture of salts: every person may ascertain them merely by observing what salts are insoluble.

It ought to be observed, however, that the precipitation takes place, not because the salts are insoluble in water, but because they are insoluble in the particular solution in which the precipitate appears. Now if this solution happens to be capable of dissolving any particular salt, that salt will not precipitate, even though it be insoluble in water. Hence the reason why precipitates so often disappear when there is present in the solution an excess of acid, of alkali, &c.

This law has been still further generalized by Berthollet. When different salts are mixed together, they separate either spontaneously, or on evaporation, according to the order of their solubility. Those which are insoluble precipitate immediately on the mixture, and those which are least soluble crystallize first when the solution is evaporated. Potass forms with sulphuric acid a salt much less soluble than sulphat of soda. Hence the reason why it has been supposed to have a stronger affinity for sulphuric acid, and by analogy for acids in general, than soda: For if sulphat of soda be mixed with the greater number of the salts of potass, sulphat of potass is obtained by evaporation.

But in cases where two salts are mixed together, the resulting salts are much influenced by the proportions of the ingredients. The same salts are not obtained if the ingredients be mixed in one proportion that would be obtained if they were mixed in another proportion. This will appear evidently from the following experiments of Berthollet.

Salts Mixed.	Proportions.	Precipitate.	First Evaporation.	Second Evaporation.	Mother Water.
Nitrat of lime Sulphat of potass	1 1	Sulphat of lime	Nitrat of potass Sulphat of lime	A little sulphat of potass.	Little
Ditto	1 2	Ditto	Sulphat of potass Sulphat of lime	Nitrat of potass Sulphat of potass Sulphat of lime	Very little
Ditto	2 1	Ditto	Sulphat of lime Nitrat of potass	Nitrat of potass A very little sulphat of lime.	Abundant*
Sulphat of soda Nitrat of lime	1 1	Sulphat of lime	Nitrat of soda	Nitrat of soda	Abundant†
Ditto	2 1	Ditto	Ditto	Ditto	Abundant‡

* Composed of nitrat of lime and nitrat of potass.
† Composed probably of sulphat and nitrat of soda.
‡ Composed of nitrat of soda and of lime.

Salts Mixed.	Proportions.	First Evaporation.	Second Evaporation.	Third Evaporation.	Mother Water.
Sulphat of soda Nitrat of potass	1 1	Sulphat of potass A little nitrat of potass	Nitrat of potass Some sulphat of potass	Nitrat of soda Some nitrat of potass	Considerable*
Ditto	2 1	Sulphat of potass	Sulphat of potass Some nitrat of potass	Sulphat of potass Nitrat of potass Nitrat of soda	Considerable*
Nitrat of potass Muriat of lime	1 1	Nitrat of potass	Muriat of potass Some nitrat of do.		Abundant†
Ditto	1 2	Muriat of potass			Abundant†
Muriat of potass Nitrat of lime	1 1	Nitrat of potass Some muriat of do.	Muriat of potass Some nitrat of do.		Abundant‡
Sulphat of potass Muriat of magnesia	1 1	Sulphat of potass	Sulphat of potass Muriat of do. Sulph of pot. & mag.	Muriat of potass Sulph. of magnesia	Considerable‡
Ditto	1 2	Ditto	Muriat of potass Sulphat of potass-and-magnesia	Ditto	Ditto

* Contained both salts. † Composed of nitrat and muriat of lime. ‡ Composed of all the saline ingredients.

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The mother water, or the liquid which remains when mixtures of salts are separated by crystallization, always contains several salts, or rather their component parts, which are prevented from crystallization by their mutual action on each other. Hence the quantity of this mother water is always the greater the more soluble the salts are; that is to say, the less disposition they have to crystallize.

CHAP. IV.

OF REPULSION.

In the three preceding Chapters, the properties of affinity, or of the attraction which influences the particles of bodies, have been examined. But besides attraction, matter possesses another force equally powerful, and equally obvious, and which acts as important a part in the phenomena of nature. This force is *repulsion*, which is no less interesting to the chemical philosopher than attraction, as it is often the antagonist of affinity, and is the chief agent in combustion, fulmination, detonation, evaporation, and indeed in the greater number of the most astonishing and tremendous phenomena of chemistry. It would be improper therefore to leave the general doctrines of chemistry without examining the present state of our knowledge of the laws of repulsion.

Chap. IV.

Proofs of a repulsive force.

1. That there is a force which opposes the approach of bodies towards each other, and which tends to separate them farther from each other, is obvious from the slightest view of the phenomena of nature. When we present the north pole of a magnet A to the same pole of another magnet B, suspended on a pivot, and at liberty to move, the magnet B recedes as the other approaches; and by following it with A at a proper distance, it may be made to turn round on its pivot with considerable velocity. In this case there is evidently some force which opposes the approach of the north poles of A and B, and which causes the moveable magnet to retire before the other. There is then a *repulsion* between the two magnets, a repulsion which increases with the power of the magnets; and this power has been made so great, by a proper combination of magnets, that all the force of a strong man is insufficient to make the two north poles touch each other. The same repulsion is equally obvious on electrical bodies; and indeed it is by means of it alone that the quantity of electricity is measured by philosophers. If two cork balls be suspended from a body with silk threads, so as to touch each other: if we charge the body with electricity, the cork balls separate from each other, and stand at a distance proportional to the quantity of electricity with which the body is charged: the balls of course repel each other.

But it is not in electric and magnetic bodies only that repulsion is perceived: Newton has shewn that it exists also between two pieces of glass. He found that when a convex lens was put upon a flat glass, it remains at the distance of the $\frac{1}{1\,1\,1}$th part of an inch, and a very considerable pressure is required to diminish

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this distance; nor does any force which can be applied bring them into actual mathematical contact: a force may indeed be applied sufficient to break the glasses in pieces, but it may be demonstrated that it does not diminish their distance much beyond the $\frac{1}{1000}$th part of an inch. There is therefore a force of repulsion which prevents the two glasses from touching each other. Boscovich has demonstrated, that the same repulsion exists between all hard elastic bodies. When an ivory ball sets another in motion by impinging against it, an equal quantity of its own motion is lost, as is well known. Now Boscovich has shewn, that the ball at rest begins to move while the other is still at a distance.

Thus we see that there exists a repulsion between a great variety of bodies; that this repulsion acts while they are at a distance from each other; that it opposes their approach towards each other; and that it increases as the distance between them diminishes. But this force not only displays itself in bodies of considerable magnitude, it is exerted also by the particles of bodies. That the particles of *air* repel each other is evident; for a considerable force is required to keep them as near each other as we find them at the surface of the earth; and when this force is removed, they separate from each other, that is to say, the air expands. Nor is it known how far this expansion extends. Air has been artificially expanded to 3000 times its usual bulk, and doubtless at great heights in the atmosphere its expansion is still much greater than that. On the other hand, air may be forcibly condensed, that is to say, its particles may be made to approach nearer each other; but a considerable force is required to produce this effect; and

this force increases nearly as the density: if it be removed, the particles again separate, and the air assumes its former bulk. What are the limits of this condensation is not known; but air has been forcibly compressed to 1cooth part of its natural bulk. Thus we see that the particles of air may be made to approach 16 times nearer each other. The elasticity of air, or the effort which it makes when compressed to resume its former bulk, is evidently the consequence of a repulsive force which its particles exert. All gaseous fluids possess the same repulsive force, and are indebted to it for their elasticity.

The particles of solid elastic bodies likewise repel each other; for they also, when forcibly compressed, resume their former size, and of course their particles repel each other. It has been demonstrated by philosophers, that all liquids are capable of a certain degree of compression, and that when the compressing force is removed they resume their former bulk; consequently the particles of these bodies also repel each other. Farther, it has been shown formerly, that the particles of no body whatever are in mathematical contact; in every case there is a distance between them. Since this is the case, it is obvious that it is possible for these particles to approach nearer each other. But if we make the attempt, we find that all bodies resist compression; many resist it so strongly, that we can produce no sensible change in their size. Consequently there must be some force which opposes the particles of all bodies approaching nearer each other than a certain distance; that is to say, that the particles of all bodies at certain distances repel each other.

2. All bodies then possess a *repulsive force* at cer-

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tain distances, which opposes the diminution of these distances. The cause, or the nature of this force, is equally inscrutable with that of *attraction*, but its existence is undoubted. Like attraction, it exerts itself, either at *sensible* distances or at *insensible* distances; of course the repulsions may be divided into two classes.

Sensible repulsion.

3. *Sensible* repulsion may very possibly be exerted by two bodies placed at immense distances from each other, as Boscovich has supposed, even beyond the sphere of the attraction of gravitation; but we have no proof of the existence of any such repulsion, unless the permanency of the universe, unaltered by that gravitation which ought to make the different systems gradually approach each other, be considered as a proof. The only sensible repulsions with which we are acquainted take place at much smaller distances. They may be reduced to two kinds, namely, *electricity* and *magnetism*. It has been ascertained that bodies possessed of the same kind of electricity repel each other, and likewise the same magnetic poles of bodies repel each other; while, on the other hand, differently electrified bodies and the different poles of magnetic bodies attract each other. Repulsion increases, as far as has been ascertained, inversely as the square of the distance; consequently at the point of contact it is infinite.

Insensible repulsion,

4. *Insensible* repulsion is most conspicuous in elastic fluids, as air and the gases; but it is exhibited also by elastic bodies in general. In these, if a judgment can be formed from the experiments on air, the repulsion increases nearly at the rate of $\frac{1}{a^3}$.

5. Electric and magnetic repulsion is supposed to reside in a fluid, or rather in two fluids, the particles of

each of which repel those which are similar to themselves, but attract the particles of the other fluid. Insensible repulsion is intimately connected with caloric; a body which has been already examined, and which seems to consist of particles that mutually repel each other. It is well known that the elasticity of air and all other gaseous bodies is increased by heat; or more accurately, that the repulsion between the particles of air, the distance remaining the same, increases with the temperature, so that at last it becomes so great as to overcome every obstacle which can be opposed to it. On the other hand, this repulsion diminishes with the temperature; the consequence of which is, that the external pressure remaining the same, the air is unable to resist it as usual, and of course its particles approach nearer each other.

Either inherent in all matter,

6. Insensible repulsion may either be a force inherent in the particles of bodies, or it may belong exclusively to some particular body combined with these particles. The first of these hypotheses seems to have been adopted by Newton. In the 31st query at the end of his *Optics*, he gives us his opinion concerning the constitution of nature. He supposes that the primitive particles of matter are similar, extremely hard and dense, and that by their combination they form all the different bodies with which we are acquainted. That these particles have been endowed by their Creator with a certain force, in consequence of which they act mutually on each other, and occasion all the phenomena of the material world; that this force changes with the distance of the particles, not only its intensity, but also its nature; that the particles when at one distance attract, but when this distance is increased or diminished to

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a certain extent, the attraction vanishes and repulsion succeeds it.

The ideas of this illustrious philosopher were only delivered in general terms, without applying them to the explanation of particular phenomena. But in 1758, Boscovich published his *Theoria Philosophiæ Naturalis*, in which he gives a detailed explanation of the economy of nature, in principles fundamentally the same with those of Newton, but new modelled with so much ingenuity, and supported by such excellent metaphysical and mathematical reasoning, that he made them entirely his own, and deservedly acquired the reputation of one of the greatest philosophers of the age. According to him, the particles of matter, or the atoms of which all bodies are composed, are mere mathematical points, destitute of extension and magnitude, but capable of acting on each other with a force which differs in intensity and in kind according to the distance. At sensible distances the force is attractive, and diminishes inversely as the square of the distance. At the smallest distances the force is repulsive; it increases as the distance diminishes, and at last becomes infinite or insuperable; so that absolute contact of course is impossible. The space between this last repulsive distance and sensible distances is divided into an indefinite number of parts, alternately attractive and repulsive. Thus let us suppose it divided into ten such parts: while the particles are at any distance between 9 and 10, that is to say, greater than 9 but less than 10, they repel; between 8 and 9 they attract; between 7 and 8 they repel; between 6 and 7 they attract, and so on. At the distances 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, which are the limits between these attracting and repelling spaces, they neither attract

nor repel. The happy explanation which this theory enables Boscovich to give of the greater number of natural phenomena is really astonishing; but there are phenomena which refuse to submit themselves to this ingenious theory; particularly those numerous changes operated on bodies by the action of caloric.

Or confined to a peculiar substance.

7. Other philosophers have supposed that repulsion is not a property inherent in all matter, but confined to a peculiar substance which has been generally considered as caloric. According to this hypothesis, there are two kinds of matter, one whose particles attract, another whose particles repel. Let us call the first *cohesive matter* and the other *caloric;* and let us suppose also, what must be the case, that cohesive matter and caloric attract each other with a force which varies as some power or function of the distance. In that case we have, 1. The particles of cohesive matter attracting each other, as $\frac{1}{d^x} + a$. 2. The particles of cohesive matter attracting caloric, as $\frac{1}{d^y} + b$. 3. The particles of caloric repelling each other, as $\frac{1}{d^z} + c$. To make the case as simple as possible, let us suppose a, b, and c, each $= 0$. The simplest inspection of the phenomena of nature is sufficient to convince us, that of the three quantities y, x, and z, x must be the least, and that y and z cannot differ much from each other. In order to form something like a precise notion of the subject, let us suppose $x = 2$ and y and z each $= 3$.

Every particle of adhesive matter must be combined with a particle of caloric, and these two must be in actual mathematical contact; for without this supposi-

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tion the phenomena of nature would be inexplicable. Every particle of adhesive matter may also be surrounded with an atmosphere of caloric, which atmospheres will necessarily diminish and alter entirely in the arrangement of the particles which compose them as the two particles of adhesive matter approach each other.

Let us suppose two particles of adhesive matter combined each with a particle of caloric acting upon each other at different distances. The variation of the different attractions and repulsions may be represented by fig. 38. Let the line AB represent the different distances of the two compound particles from each other; one of the particles remaining stationary in A, while the other is moving towards B. The ordinates $m\,b$, $n\,c$, $o\,d$, $p\,e$, $q\,f$, $r\,g$, $s\,h$, $t\,i$, $u\,k$, $x\,l$, represent the attractive forces when the second particle is at the points m, n, o, p, q, r, s, t, u, x, respectively; and the ordinates $m\,b'$, $n\,c'$, $o\,d'$, &c. represent the repulsive forces at the same points. The curves $c\,d\,e\,f\,g\,h\,i\,k\,l$, and $c'\,d'\,e'\,f'\,g'\,h'\,i'\,k'\,l'$, drawn through the extremities of these ordinates, are the curves of repulsion and attraction. The properties of these curves have been investigated by mathematicians; but it is unnecessary to have recourse to their investigation, as a bare inspection of the figure is sufficient to demonstrate that it is altogether irreconcileable with the phenomena of nature: For since the ordinates of the repulsive curve diminish at a greater rate than those of the attractive, at some particular distance from A they will be equal to each other. Let us suppose them to be equal at r, and let $A\,r = 6$, and $r\,g$ or $r\,g' = 1$. Let $A\,m = 1$, $A\,n = 2$, $A\,o = 3$, $A\,p = 4$, &c. Then at the points m, n, o, p, &c. we have the repul-

sive and attractive ordinates equal nearly to the following numbers:

	m	*n*	*o*	*p*	*q*	*r*	*s*	*t*	*u*	*x*
Repuls.	216.00	27.00	7.90	3.20	1.70	1.00	6.2	4.2	2.9	2.1
Attract.	39.60	9.00	4.00	2.20	1.40	1.00	7.3	5.6	4.4	3.6

Now as these forces are opposed to each other, they partly destroy each other; therefore to find the absolute force by which the two compound particles are repelled or attracted, while the second compound particle is in the points *m*, *n*, *o*, &c. we have only to take the difference between the attracting and repelling ordinates at these points. This gives us the following result:

	m	*n*	*o*	*p*	*q*	*r*	*s*	*t*	*u*	*x*
Rep.	176.40	18.00	3.90	1.00	3.00	0				
Attr.						0	0.11	0.14	0.15	0.15

The point *r* is evidently a point of cohesion; as the two particles, when at the distance denoted by it, are neither attracted nor repelled. But the attractions which follow are totally incompatible with the phenomena; For, instead of diminishing as $\frac{1}{d^2}$, they diminish at an incomparably slower rate. The same remark applies to the repulsions.

We are absolutely certain, then, that x and y are not $= 2$ and 3. They must be such, that the difference between $\frac{1}{d^x}$ and $\frac{1}{d^y}$ is a square; that is to say, we must have $\frac{1}{d^y} - \frac{1}{d^x} = \frac{1}{d^2}$, for that alone corresponds with the phenomena. The fact is, if the above supposition, that there are two kinds of matter, one repelling and another attracting, be adopted, it is obvious that the rate at which we see the attractions and repulsions of bodies to

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vary, is only the difference between the respective forces which the particles of matter possess. Of course we cannot ascertain these forces except indirectly. Thus if we suppose $x = 3$, and $y = 5$, and that the two forces are equal as before at the point r; that is, let $r\,g$ or $r\,g' = a$, then the attractions and repulsions in the different points will be as follows:

	m	n	o	p	q	r	s	t	u	x
Rep.	$\frac{6^5}{1^5}a$	$\frac{6^5}{2^5}a$	$\frac{6^5}{3^5}a$	$\frac{6^5}{4^5}a$	$\frac{6^5}{5^5}a$	a	$\frac{6^5}{7^5}a$	$\frac{6^5}{8^5}a$	$\frac{6^5}{9^5}a$	$\frac{6^5}{10^5}a$
Attr.	$\frac{6^3}{1^3}a$	$\frac{6^3}{2^3}a$	$\frac{6^3}{3^3}a$	$\frac{6^3}{4^3}a$	$\frac{6^3}{5^3}a$	a	$\frac{6^3}{7^3}a$	$\frac{6^3}{8^3}a$	$\frac{6^3}{9^3}a$	$\frac{6^3}{10^3}a$
Rep.	$\frac{6^2}{1^2}a$	$\frac{6^2}{2^2}a$	$\frac{6^2}{3^2}a$	$\frac{6^2}{4^2}a$	$\frac{6^2}{5^2}a$	o				
Attr.						o	$\frac{6^2}{7^2}a$	$\frac{6^2}{8^2}a$	$\frac{6^2}{9^2}a$	$\frac{6^2}{10^2}a$

Here the rate of variation is always as $\frac{1}{d^2}$. The attractive and repulsive curves would assume a very different form from those in the figure. But it is needless to examine the subject farther, as it would be necessary to shew, before admitting the hypothesis, that the repulsion varies at the rate of $\frac{1}{d^2}$. If this could be proved, the greater number of the phenomena of nature could be explained, upon this hypothesis, with the same facility as that of Boscovich; and it would have the additional advantage of not assuming the existence of any force whose action is not actually demonstrated by the phenomena. It is obvious that the changes from attractions to repulsion, when more than one such change appears in consequence of varying the distance between bodies, may be accounted for by supposing that part of

the caloric is driven off by the approach of the bodies.

8. Before leaving this subject, it will be worth while to shew, by an example, that the repulsion between the particles of caloric often acts as a real chemical force, and that it affords a key to explain several phenomena which at first sight appear nearly contradictory. Why do bodies require different temperatures in order to unite? and Why does the presence of caloric, in many cases, favour, or rather produce, union, while it prevents or destroys it in others?

Some substances, phosphorus for instance, combine with oxygen at the common temperature of the atmosphere; others, as carbon, require a higher temperature; and others, as hydrogen and azotic gas, do not combine except at a very high temperature. To what are these differences owing?

It is evident, that whatever diminishes the cohesion which exists between the particles of any body, must tend to facilitate their chemical union with the particles of other bodies: this is the reason that bodies combine more easily when held in solution by water, or when they have been previously reduced to a fine powder. Now caloric possesses the property of diminishing cohesion. And one reason why some bodies require a high temperature to cause them to combine is, that at a low temperature the attraction of *cohesion* is in them superior to that of affinity; accordingly, it becomes necessary to weaken that attraction by caloric till it becomes inferior to that of affinity. The quantity of caloric necessary for this purpose must vary according to the strength of the cohesion and of the affinity; it must be inversely as the affinity, and directly as the cohesion. Wherefore, if we knew precisely the force of the cohe-

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sion between the particles of any body, and of the affinity between the particles of that body and of any other, we could easily reduce the temperature necessary to calculation.

That caloric or temperature acts in this manner, cannot be doubted, if we consider that other methods of diminishing the attraction of cohesion may be substituted for it with success. A large lump of charcoal, for instance, will not unite with oxygen at so low a temperature as the same charcoal will do when reduced to a very fine powder; and charcoal will combine with oxygen at a still lower temperature, if it be reduced to its integrant particles, by precipitating it from alcohol, as Dr Priestley did by passing the alcohol through red hot copper. And to shew that there is nothing in the nature of oxygen and carbon which renders a high temperature necessary for their union, if they be presented to each other in different circumstances, they combine at the common temperature of the atmosphere; for if nitric acid, at the temperature of 6°, be poured upon charcoal powder, well dried in a close crucible, the charcoal takes fire, owing to its combining with the oxygen of the acid *: And in some other situations, carbon is so completely divided that it is capable of combining with the oxygen of the atmosphere, or, which is the same thing, of catching fire at the common temperature: this seems to be the case with it in those pyrophori that are formed by distilling to dryness several of the neutral salts which contain acetous acid †. These observations are sufficient to shew, that

* Proust and Morveau, *Encyc. Method. Chim.* i. 474.

† Morveau, Ibid.

caloric is in many cases necessary in order to diminish the attraction of *cohesion*.

But there is a difficulty still remaining: How comes it that certain bodies will combine with oxygen without the assistance of any foreign heat, provided the combination be once begun, though a quantity of caloric is necessary to begin the combination? and that other bodies require to be surrounded by a great quantity of caloric during the whole time of their combining with oxygen? Alcohol, for instance, if once killed, burns till it is quite consumed; and this is the case with oils also, provided they be furnished with a wick.

We would err very much, were we to suppose that a high temperature is not as necessary to these substances during the whole of their combustion as at the commencement of it; for Mr Monge found, on making the trial, that a candle would not burn after the temperature of the air around it was reduced below a certain point.

All substances which continue to burn after being once kindled are *volatile*, and they burn the easier in proportion to that volatility. The application of a certain quantity of caloric to alcohol volatilizes part of it; that is to say, diminishes the attraction of its cohesion so much that it combines with oxygen. The oxygen which enters into this combination gives out as much heat as volatilizes another portion of the alcohol; which combines with oxygen in its turn; more heat is given out; and thus the process goes on. Oils and tallow exhibit the very same phenomena, only as they are less volatile, it is necessary to assist the process by means of the capillary attraction of the wick, which confines the action of the caloric evolved to a small quantity of oil, and thus enables it to produce the proper effect. In

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short, then, every substance which is capable of continuing to burn after being once kindled is volatile, or capable of being converted into vapour by the degree of heat at first applied. The reason that a live coal will not burn when suspended insulated in the air, is not, as Dr Hutton supposed*, because its *light* is dissipated; but because the coal cannot be converted into vapour by the degree of heat which it contains, and because the cohesion of its particles is too great to allow it to combine with oxygen without some such change. There are some coals, however, which contain such a quantity of bitumen that they will burn even in the situation supposed by Dr Hutton, and continue to burn, provided they be furnished with any thing to act as a wick. It is needless to add, that bitumen, like oil, is easily converted into vapour.

But this explanation, instead of removing our difficulties, has only served to increase them: For if caloric only acts by diminishing the attraction of cohesion, and converting these substances into vapour, why do not all elastic fluids combine at once without any additional caloric? why do not oxygen and hydrogen, when mixed together in the state of gas, unite at once and form water? and why do not oxygen and azote, which are constantly in contact in the atmosphere, unite also and form nitrous gas? Surely it cannot be the attraction of cohesion that prevents this union. And if it be ascribed to their being already combined with caloric, how comes it that an additional dose of one of the ingredients of a compound decomposes it? Surely, as Mr Monge has observed, this is contrary to all the other operations in chemistry.

* *On Light and Heat.*

That the particles of fluids are not destitute of an attraction for each other, is evident from numberless facts. The particles of water drew one another after them in cases of capillary attraction; which is probably owing to the attraction of cohesion. It is owing to the attraction of cohesion, too, that small quantities of water form themselves into spheres; nor is this attraction so weak as not to be perceptible. If a small plate of glass be laid upon a globule of mercury, the globule, notwithstanding the pressure, continues to preserve its round figure. If the plate be gradually charged with weights one after another, the mercury becomes thinner and thinner, and extends itself in the form of a plate; but as soon as the weights are removed, it recovers its globular figure again, and pushes up the glass before it. Here we see the attraction of cohesion, not only superior to gravitation, but actually overcoming an external force *. And if the workman, after charging his plate of glass with weights, when he is forming mirrors, happen to remove these weights, the mercury which had been forced from under the glass, and was going to separate, is drawn back to its place, and the glass again pushed up. Nor is the attraction of cohesion confined to solids and liquids; it cannot be doubted, that it exists also in gases; at least it is evident, that there subsists an attraction between gases of a different kind: for although oxygen and azotic gas are of different gravities, and ought therefore to occupy different parts of the atmosphere, we find them always mixed together; and this can only be ascribed to an attraction.

* Morveau, *Encycl. Meth Affinité*, p. 543.

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It seems evident, in the first place, that the affinity between the bases of the gases under consideration and oxygen is greater than their affinity for that dose of caloric which produces their elastic form; for when they are combined with oxygen, the same dose will not separate them again. Let us take hydrogen for an instance: The affinity of hydrogen is greater for oxygen than for the caloric which gives it its gaseous form; but the oxygen is also combined with caloric, and there exists an attraction of cohesion between the particles of the hydrogen gas and oxygen gas; the same attraction subsists between those of oxygen gas and hydrogen gas. Now the sum of all these affinities, namely, the affinity between hydrogen and caloric, the affinity between oxygen and caloric, the cohesion of the particles of the hydrogen, and the cohesion of the particles of oxygen—is greater than the affinity between the hydrogen and oxygen; and therefore no decomposition can take place. Let the affinity between

Oxygen and caloric be	50
Hydrogen and caloric	50
Cohesion of oxygen for hydrogen	4
Cohesion of hydrogen	2
Sum of quiescent affinities	106
The affinity of oxygen and hydrogen	105

The quiescent affinities being greater than the divellent affinities, no decomposition can take place.

Let now a quantity of caloric be added to the oxygen and hydrogen gas, it has the property of expanding them, and of course of diminishing their cohesion; while its affinity for them is so small that it may be neglected. Let us suppose that it diminishes the cohesion

of the oxygen 1, and of the hydrogen also 1, their cohesion will now be 3 and 1; and the quiescent affinities being only 104, while the divellent are 105, decomposition would of course take place, and a quantity of caloric would thus be set at liberty to produce the same effects upon the neighbouring particles.

Thus, then, caloric acts only by diminishing cohesion: And the reason that it is required so much in gaseous substances, and in those combinations into which oxygen enters, is the strong affinity of oxygen and the other bases of the gases for caloric; for, owing to the repulsion which exists between the particles of that subtile substance, an effect is produced by adding large doses of it, contrary to what happens in other cases. The more of it is accumulated, the stronger is the repulsion between its particles; and therefore the more powerful is its tendency to fly off: and as this tendency is opposed by its affinity for the body and the cohesion of its particles, it must diminish both these attractions.

PART II.

CHEMICAL EXAMINATION

OF

NATURE.

HAVING, in the First Part of this Work, given a very full detail of the Principles of Chemistry, and a description of the different Substances with which it is necessary for the Chemist to be acquainted, I propose, in this Second Part, to take a view of the different substances as they exist in nature, constituting the material world, that we may ascertain how far the science of chemistry will contribute towards explaining their nature, and accounting for the different changes which they produce on each other. Now the different substances of which the material world, as far as we have access to it, is composed, may be very conveniently arranged under the five following heads:

1. The Atmosphere,
2. Waters,
3. Minerals,
4. Vegetables,
5. Animals.

These five divisions will form the subject of the five following Books.

BOOK I.

OF

THE ATMOSPHERE.

Book I.

THE atmosphere is that invisible elastic fluid which surrounds the earth to an unknown height, and encloses it on all sides. It received its name from the Greeks, in consequence of the vapours which are continually mixing with it. When the chemist turns his attention to the atmosphere, there are two things which naturally engage his attention: First, to ascertain the substances of which it is composed; and, secondly, to trace the changes to which it is liable. I shall therefore divide this Book into two Chapters. In the first, I shall examine the component parts of the atmosphere; and, in the second, examine the changes to which it is liable under the title of METEOROLOGY.

CHAP. I.

COMPOSITION OF THE ATMOSPHERE.

Opinions of the ancients.

NEITHER the properties nor the composition of the atmosphere seem to have occupied much of the attention of the ancients. Aristotle considered it as one of the four elements, situated between the regions of *water* and *fire*, and mingled with two *exhalations*, the *dry* and the *moist*; the first of which occasioned thunder, lightning, and wind; while the second produced rain, snow, and hail. The ancients, in general, seem to have considered the blue colour of the sky as essential to the atmosphere; and several of their philosophers believed that it was the constituent principle of other bodies, or at least that air and other bodies are mutually convertible into each other *. But these opinions continued in the state of vague conjectures, till the matter was explained by the sagacity of Hales and of those philosophers who followed his illustrious career.

* Thus Lucretius:

Semper enim quodcunque fluit de rebus, id omne
Aeris in magnum fertur mare: qui nisi contra
Corpora retribuat rebus, recreetque fluenteis,
Omnia jam resoluta forent, et in aera versa.
Haud igitur cessat gigni de rebus et in res
Recidere assidue, quoniam fluere omnia constat. *Lib.* v. 274.

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Discoveries of the moderns.

It was not till the time of Bacon, who first taught mankind to investigate natural phenomena, that the atmosphere began to be investigated with precision. Galileo introduced the study by pointing out its weight; a subject which was soon after investigated completely by Torricelli, Paschal, &c. Its density and elasticity were ascertained by Boyle and the Florence Academicians. Mariotte measured its dilatibility; Hooke, Newton, Boyle, Derham, pointed out its relation to light, to sound, and to electricity. Newton explained the effect produced upon it by moisture; from which Halley attempted to explain the changes in its weight indicated by the barometer. But a complete enumeration of the discoveries made upon the atmosphere in general belongs to *pneumatics;* a science which treats professedly of the mechanical properties of air.

Component parts of the atmosphere.

The knowledge of the component parts of the atmosphere did not keep pace with the investigation of its mechanical properties. The opinions of the earlier chemists concerning it are too vague and absurd to merit any particular notice. Boyle, however, and his contemporaries, put it beyond doubt that the atmosphere contained two distinct substances. 1. An elastic fluid distinguished by the name of *air*. 2. Water in the state of vapour. Besides these two bodies, it was supposed that the atmosphere contained a great variety of other substances, which were continually mixing with it from the earth, and which often altered its properties, and rendered it noxious or fatal. Since the discovery of carbonic acid gas by Dr Black, it has been ascertained that this elastic fluid always constitutes a part of the atmosphere. The constituent parts of the atmosphere therefore are,

1. Air,
2. Water,
3. Carbonic acid gas,
4. Unknown bodies.

These shall form the subject of the four following Sections. But before proceeding to ascertain their properties, and the proportion in which they exist in air, it will be worth while to endeavour to calculate the amount of the whole of the atmosphere which surrounds the earth. This will put it in our power to state the amount of its different constituent parts, and of course to see how far the quantities of each agree with the different chemical theories which have been maintained concerning the influence of these bodies on the different kingdoms of nature.

Its absolute quantity.

Mechanical philosophers have demonstrated, that the weight of a column of the atmosphere, whose base is an inch square, is equal to a column of mercury of the same base, and balanced by the atmosphere in the barometrical tube. Now let us suppose the mean height of the barometer to amount to nearly 30 inches. Let R denote the radius of the earth, r the height of the mercury in the barometer, π the ratio between the circumference of a circle and its diameter. The solidity t he earth is $\frac{4\pi R^3}{3}$; the solidity of the sphere composed of the earth, and a quantity of mercury surrounding it equal to the weight of the atmosphere, is $\frac{4\pi(R+r)^3}{3}$. Consequently the solidity of the hollow sphere of mercury equal to the weight of the atmosphere, is $\frac{4\pi(R+r)^3}{3} - \frac{4\pi R^3}{3} = 4\pi\left(R^2 r + r^2 R + \frac{r^3}{3}\right)$, or, neglecting the terms containing r^2 and r^3,

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$4\pi R^2 r$. This formula, by substituting for π, R^2, and r, their known values, gives us the solidity of the hollow sphere of mercury in cubic feet. But a cubic foot of mercury is nearly equal to 135,000 avoirdupois ounces. Hence the mean weight of the atmosphere amounts to about 11,911,163,227,258,181,818 lbs. avoirdupois.

SECT. I.

OF AIR.

Air an elastic fluid.

THE word AIR seems to have been used at first to denote the atmosphere in general; but philosophers afterwards restricted it to the elastic fluid, which constitutes the greatest and the most important part of the atmosphere, excluding the water and the other foreign bodies which are occasionally found mixed with it. For many years all permanently elastic fluids were considered as air, from whatever combinations they were extricated, and supposed to possess exactly the same properties with the air of the atmosphere. It is true, indeed, that Van Helmont suspected that elastic fluids possessed different properties; and that Boyle ascertained that all elastic fluids were not capable of supporting combustion like air. But it was not till the discoveries of Cavendish and Priestley had demonstrated the peculiar properties of a variety of elastic fluids, that philosophers became sensible that there existed a variety of species of them. In consequence of this discovery, the

word *air* became generic, and was applied by Priestley, and the British and Swedish philosophers in general, to all permanently elastic fluids, while the air of the atmosphere was distinguished by the epithets of *common* or *atmospheric* air: but Macquer thought proper to apply the term *gas*, first employed by Van Helmont, to all permanently elastic fluids except common air, and to confine the term *air* to this last fluid. This innovation was scarcely necessary; but as it has now been generally adopted, it will be proper to follow it. By the word *air*, then, in this Section, I mean only common *air*, or the fluid which forms by far the greatest part of the atmosphere. Chap. I.

The foreign bodies which are mixed or united with air in the atmosphere are so minute in quantity compared to it, that they have no very sensible influence on its properties. We may therefore consider atmospheric air, when in its usual state of dryness, as sufficiently pure for examination.

Specific gravity.

1. Air is an elastic fluid, invisible indeed, but easily recognised by its properties. Its specific gravity, according to the experiments of Sir George Shuckburgh, when the barometer is at 30 inches, and the thermometer between 50° and 60°, is 0.0012, or 816 times lighter than water. One hundred cubic inches of air weigh 31 grains troy.

Density.

But as air is an elastic fluid, and compressed at the surface of the earth by the whole weight of the incumbent atmosphere, its density diminishes according to its height above the surface of the earth. From the experiments of Paschal, Deluc, General Roy, &c. it has been ascertained, that the density diminishes in the ratio of the compression. Consequently the density de-

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creases in a geometrical progression, while the heights increase in an arithmetical progression.

Bouguer had suspected, from his observations made on the Andes, that at considerable heights the density of the air is no longer proportional to the compressing force * ; but the experiments of Saussure junior, made upon Mount Rose, have demonstrated the contrary †.

Dilatability. 2. Air is dilated by heat. From the experiments of General Roy and Sir George Shuckburgh, compared with those of Trembley, &c. it appears that, at the temperature of 60°, every degree of temperature increases the bulk of air about $\frac{1}{8\frac{1}{2}}$ part. But the experiments of Du Vernois and Morveau, which gives us the dilatation of air for every degree of Reaumur from 0° to 80°, have been given in a former part of this Work, and they are the most complete which have hitherto appeared.

3. The specific caloric of air, according to the experiments of Dr Crawford, is 1.79.

Colour. 4. Although the sky is well known to have a blue colour, yet it cannot be doubted that air itself is altogether colourless and invisible. The blue colour of the sky is occasioned by the vapours which are always mixed with the air, and which have the property of reflecting the blue rays more copiously than any other. This has been proved by the experiments which Saussure made with his *cyanometer* at different heights above the surface of the earth. This consisted of a circular band of paper, divided into 51 parts, each of which were painted with a different shade of blue; beginning with

* *Mem. Par.* 1753, p. 515. † *Jour. de Phys.* xxxvi. 98.

the deepest mixed with black, to the lightest mixed with white. He found that the colour of the sky always corresponds with a deeper shade of blue the higher the observer is placed above the surface; consequently, at a certain height, the blue will disappear altogether, and the sky appear black; that is to say, will reflect no light at all. The colour becomes always lighter in proportion to the vapours mixed with the air. Hence it is evidently owing to them*.

5. The property which the air has of supporting combustion, and the necessity of it for respiration, are too well known to require any description.

Composition.

6. For many ages air was considered as an element or simple substance. For the knowledge of its component parts, we are indebted to the labours of those philosophers in whose hands chemistry advanced with such rapidity during the last forty years of the 18th century. The first step was made by Dr Priestley in 1774, by the discovery of oxygen gas. This gas, according to the prevailing theory of the time, he considered as air totally deprived of phlogiston; azotic gas, on the other hand, was air saturated with phlogiston. Hence he considered common air as oxygen gas combined with an indefinite portion of phlogiston, varying in purity according to that portion; being always the purer the smaller a quantity of phlogiston it contained.

While Dr Priestley was making experiments on oxygen gas, Scheele proceeded to the analysis of air in a different manner. He observed that the liquid sulphurets, phosphorus, and various other bodies, when con-

* Saussure's *Voyages dans les Alpes*, iv. 288.

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fined along with air, have the property of diminishing its bulk; and this diminution always amounts to a certain proportion, which he found to be between a third and a fourth part of the whole. The residuum was unfit for supporting flame, and was not diminished by any of the processes which diminish common air. To this residuum he gave the name of *foul air*. From these experiments, he concluded that air is a compound of two different elastic fluids: namely, *foul air*, which constitutes more than two thirds of the whole, and *another air*, which is alone capable of supporting flame and animal life. This last air he extricated from nitre by heat, from the black oxide of manganese, and from other substances, and gave it the name of *empyreal air*. He shewed that a mixture of two parts of foul air and one part of empyreal air possesses the properties of common air *.

The foul air of Scheele was the same with the phlogisticated air of Priestley, or with what is now known by the name of *azotic gas*. His empyreal air is the same with the dephlogisticated air of Priestley, or with what is at present called *oxygen gas*. According to him, therefore, air is a compound of two parts of azotic and one part of oxygen gas. He accounted for the diminution of air by the liquid sulphurets and other similar bodies by his theory of the composition of caloric, which he considered as a compound of phlogiston and oxygen gas. According to him, the phlogiston of the sulphuret combines with the oxygen of the air, and passes through the vessels in the state of caloric, while

* Scheele on *Air and Fire*, p. 7. &c. Eng. Transl.

the azotic gas, which has no affinity for caloric, is left behind.

While Scheele was occupied with his experiments on air, Lavoisier was assiduously employed on the same subject, and was led by a different road to precisely the same conclusion as Scheele. By oxidizing mercury in a vessel filled with common air, and heated to the boiling point of mercury, he abstracted the greater part of its oxygen gas; and by heating the red oxide thus formed, he reconverted it into mercury, while at the same time a quantity of oxygen gas was extricated. The residuum in the first experiment possessed the properties of azotic gas; but when the oxygen gas extricated from the mercury was added to it, the mixture assumed again the properties of common air. Hence he concluded that air is composed of azotic gas and oxygen; and from a variety of experiments he determined the proportions to be 73 parts of azotic gas and 27 parts of oxygen gas. He demonstrated, too, that when air is diminished by liquid sulphurets, metals, &c. the oxygen gas which is abstracted combines with the sulphurets, &c. and converts them into acids or oxides according to their respective nature. But as all these experiments have been already detailed in the First Part of this Work, it is unnecessary to be more particular in this place.

Air composed of oxygen and azotic gas.

Air, then, is a compound of oxygen and azotic gas: but it becomes a question of considerable consequence to determine the proportion of these two ingredients, and to ascertain whether that proportion is in every case the same. Since azotic gas, one of the component parts of that fluid, cannot be separated by any substance with which chemists are acquainted, the analysis of air can only be attempted by exposing it to the action of

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those bodies which have the property of absorbing its oxygen. By these bodies the oxygen gas is separated, and the azotic gas is left behind, and the proportion of oxygen may be ascertained by the diminution of bulk; which, once known, it is easy to ascertain the proportion of azotic gas, and thus to determine the exact relative quantity of the component parts.

Method of ascertaining the proportion of its component parts.

After the composition of the atmosphere was known to philosophers, it was taken for granted that the proportion of its oxygen varies in different times and in different places; and that upon this variation the purity or noxious qualities of air depended. Hence it became an object of the greatest importance to be in possession of a method of determining readily the quantity of oxygen in a given portion of air. Accordingly various methods were proposed, all of them depending upon the property which a variety of bodies possesses of absorbing the oxygen of the air without acting upon its azote. These bodies were mixed with a certain known quantity of atmospheric air, in graduated glass vessels inverted over water, and the proportion of oxygen was determined by the diminution of bulk. These instruments received the name of *eudiometers*, because they were considered as measurers of the purity of air. The eudiometers proposed by different chemists may be reduced to five.

Eudiometer of Priestley and Fontana.

1. The first eudiometer was made in consequence of Dr Priestley's discovery, that when nitrous gas is mixed with air over water, the bulk of the mixture diminishes rapidly, in consequence of the combination of the gas with the oxygen of the air, and the absorption of the nitric acid thus formed by the water. When nitrous gas is mixed with azotic gas, no diminution at all takes

place. When it is mixed with oxygen gas in proper proportions, the absorption is complete. Hence it is evident that in all cases of a mixture of these two gases the diminution will be proportional to the quantity of the oxygen. Of course it will indicate the proportion of oxygen in air; and by mixing it with different portions of air, it will indicate the different quantities of oxygen which they contain, provided the component parts of air be susceptible of variation. Dr Priestley's method was to mix together equal bulks of air and nitrous gas in a low jar, and then to transfer the mixture into a narrow graduated glass tube about three feet long, in order to measure the diminution of bulk. He expressed this diminution by the number of hundred parts remaining. Thus, suppose he had mixed together equal parts of nitrous gas and air, the sum total of this mixture was 200 (or 2.00): suppose the residuum when measured in the graduated tube to amount to 104 (or 1.04), and of course that 96 parts of the whole had disappeared, he denoted the purity of the air thus tried by 104. A more convenient instrument was invented by Dr Falconer of Bath; and Fontana greatly improved this method of measuring the purity of air. A description of his eudiometer was published by Ingenhousz in the first volume of his Experiments; it was still farther improved by Cavendish in 1783*; and Humbolt has lately made a very laborious set of experiments in order to bring it to a state of complete accuracy. But after all the exertions of these philosophers, the method of analysing air by means of nitrous

* *Phil. Trans.* lxxiii. 107.

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gas is liable to so many anomalies, that it cannot be depended on.

Priestley and Fontana have proved, that the way of mixing the two airs occasions a great difference in the result; the figure of the vessels is equally important, and so is the water over which the mixture is made. And even when all these things are the same, impurity of the nitrous gas may occasion the most enormous differences in the results.

Humboldt has shewn that the nitrous gas ought to be prepared by means of nitric acid of the density 1.170; when a much stronger or weaker acid is employed, the gas produced is always contaminated with a great proportion of azotic gas. He has pointed out the solution of sulphat of iron, as proper to ascertain the purity of the nitrous gas employed, by absorbing the nitrous gas and leaving the azotic gas or other foreign gases. He has shewn that when nitrous gas of the same degree of purity is made to mix very slowly with air, the vessel being carefully agitated during the mixture, the results, provided the experiment be performed with address, correspond with each other. And he has made it probable, that when equal quantities of air and nitrous gas, so pure as to contain only about 0.1 of azotic gas mixed with it, are agitated together slowly over water, the diminution divided by 3.55 gives the quantity of oxygen contained in the air examined. But notwithstanding the ingenuity of his experiments, the anomalies attending this method are still so great as not to render it susceptible of accuracy. For that reason I think it unnecessary to give a particular description of the different eudiometers invented to ascertain the purity of air by means of nitrous gas. The result of the numerous

experiments which have been made with nitrous gas is, that the proportion of oxygen in atmospheric air varies in different places and at different times. The minimum is about 0.22, the maximum about 0.30; consequently if this method of analysing air is to be depended on, we must consider that fluid, not as a permanent chemical compound, but as a body subjected to all the variations to which accidental mixtures are liable.

Eudiometer of Volta.

2. The second kind of eudiometer was proposed by Volta. The substance employed by that philosopher to separate the oxygen from the air was hydrogen gas. His method was to mix given proportions of the air to be examined and hydrogen gas in a graduated glass tube; to fire the mixture by an electric spark; and to judge of the purity of the air by the bulk of the residuum. But this method is not susceptible of so great a degree of accuracy as the preceding, when the object is to ascertain the precise quantity of oxygen gas in a given bulk of air. For if too little hydrogen gas be mixed with the air, not only the whole of the oxygen will not be abstracted, but a portion of the azote will disappear in consequence of the formation of nitric acid. On the other hand, if too much hydrogen be added, part of it will remain after the firing of the mixture, and increase the bulk of the residuum. Volta's eudiometer, then, though it may have its uses, is scarcely susceptible of giving us the analysis of air.

Eudiometer of Scheele.

3. For the third kind of eudiometer, we are indebted to Scheele. It is merely a graduated glass vessel, containing a given quantity of air exposed to newly prepared liquid alkaline or earthy sulphurets, or to a mixture of iron-filings and sulphur, formed into a paste with water. These substances absorb the whole of the

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oxygen of the air, which converts a portion of the sulphur into an acid. The oxygen contained in the air thus examined, is judged of by the diminution of bulk which the air has undergone. This method is not only exceedingly simple, but it requires very little address, and yet is susceptible of as great accuracy as any other whatever. The only objection to which it is liable is its slowness; for when the quantity of air operated on is considerable, several days elapse before the diminution has reached its maximum.

Improved by De Marti.

But this objection has been completely obviated by Mr De Marti, who has brought Scheele's eudiometer to a state of perfection. He found that a mixture of iron filings and sulphur does not answer well, because it emits a small quantity of hydrogen gas, evolved by the action of the sulphuric acid formed by the absorption of the oxygen of the air upon the iron; but the hydrogureted sulphurets, formed by boiling together sulphur and liquid potass or lime-water, answered the purpose perfectly. These substances, indeed, when newly prepared, have the property of absorbing a small portion of azotic gas; but they lose this property when saturated with that gas, which is easily effected by agitating them for a few minutes with a small portion of atmospheric air. His apparatus is merely a glass tube, ten inches long, and rather less than half an inch in diameter, open at one end, and hermetically sealed at the other. The close end is divided into 100 equal parts, having an interval of one line between each division. The use of this tube is to measure the portion of air to be employed in the experiment. The tube is filled with water; and by allowing the water to run out gradually while the tube is inverted, and the open end kept shut

with the finger, the graduated part is exactly filled with air. These hundred parts of air are introduced into a glass bottle filled with liquid sulphuret of lime previously saturated with azotic gas, and capable of holding from two to four times the bulk of the air introduced. The bottle is then to be corked with a ground glass stopper, and agitated for five minutes. After this the cork is to be withdrawn while the mouth of the phial is under water; and for the greater security, it may be corked and agitated again. After this, the air is to be again transferred to the graduated glass tube, in order to ascertain the diminution of its bulk*.

Air, examined by this process, suffers precisely the same diminution in whatever circumstances the experiments are made: no variation is observed whether the wind be high or low, or from what quarter soever it blows; whether the air tried be moist or dry, hot or cold; whether the barometer be high or low. Neither the season of the year, nor the situation of the place, its vicinity to the sea, to marshes, or to mountains, make any difference. Mr De Marti found the diminution always between 0.21 and 0.23. Hence we may conclude that air is composed of

0.78 azotic gas
0.22 oxygen gas

1.00

Scheele indeed found, that the absorption amounted to 0.27†; but that was because he neglected to saturate his sulphuret with azotic gas; for when the portion of

* *Jour. de Phys.* lii. 176. † Scheele, ii. 1.

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azotic gas which must have been absorbed, and which has been indicated by De Marti, is subtracted, the portion of oxygen in air, as indicated by his experiments, is reduced very nearly to 0.22. The trifling variations perceptible in his experiments were no doubt owing to the quantities of the mixture of sulphur and iron, by which he abstracted the oxygen, not being exactly the same at different times; the consequence of which would be an unequal absorption of azotic gas.

Eudiometer of Berthollet.

4. In the fourth kind of eudiometer, the abstraction of the oxygen of air is accomplished by means of phosphorus. This eudiometer was first proposed by Achard *. It was considerably improved by Reboul †, and by Seguin and Lavoisier ‡; but Berthollet § has lately brought it to a state of perfection, as it is equally simple with the eudiometer of De Marti, and scarcely inferior to it in precision.

Instead of the rapid combustion of phosphorus, this last philosopher has substituted its spontaneous combustion, which absorbs the oxygen of air completely; and when the quantity of air operated on is small, the process is over in a short time. The whole apparatus consists in a narrow graduated tube of glass containing the air to be examined, into which is introduced a cylinder of phosphorus fixed upon a glass rod, while the tube stands inverted over water. The phosphorus should be so long as to traverse nearly the whole of the air. Immediately white vapours rise from the phosphorus and fill the tube. These continue till the whole of the

* *Jour. de Phys.* 1784, vol. i. † *Ann. de Chim.* xiii. 38.

‡ Ibid. ix. 293.

§ Ibid. xxxiv. 73. and *Jour. de l'Ecole Polytechn.* I. iii. 274.

oxygen combines with phosphorus. They consist of phosphorous acid, which falls by its weight to the bottom of the vessel, and is absorbed by the water. The residuum is merely the azotic gas of the air, holding a portion of phosphorus in solution. Berthollet has ascertained, that by this foreign body its bulk is increased $\frac{1}{40}$th part. Consequently the bulk of the residuum, diminished by $\frac{1}{40}$, gives us the bulk of the azotic gas of the air examined; which bulk, subtracted from the original mass of air, gives us the proportion of oxygen gas contained in it.

All the different experiments which have been made by means of this eudiometer agree precisely in their result, and indicate that the proportions of the ingredients of air are always the same; namely, about 0.22 parts of oxygen gas, and 0.78 of azotic gas. Berthollet found these proportions in Egypt and in France, and I have found them constantly in Edinburgh in all the different seasons of the year. Thus we see that the analysis of air, by means of phosphorus, agrees precisely with its analysis by means of hydrogureted sulphurets.

Eudiometer of Davy.

5. The fifth eudiometer has been lately proposed by Mr Davy. In it the substance used to absorb the oxygen from air is a solution of sulphat or muriat of iron in water, and impregnated with nitrous gas. A small graduated glass tube, filled with the air to be examined, is plunged into the nitrous solution, and moved a little backwards and forwards. The whole of the oxygen is absorbed in a few minutes. The state of greatest absorption ought to be marked, as the mixture afterwards emits a little gas which would alter the result. By means of this and the two preceding eudiometers, Mr

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Davy examined the air at Bristol, and found it always to contain about 0.21 of oxygen. Air sent to Dr Beddoes from the coast of Guinea gave exactly the same result. This eudiometer, then, corresponds exactly with the two last*.

Method of ascertaining the density of the air operated on.

In all these different methods of analysing air, it is necessary to operate on air of a determinate density, and to take care that the residuum be neither more condensed nor dilated than the air was when first operated on. If these things are not attended to, no dependance whatever can be placed upon the result of the experiments, how carefully soever they may have been performed. Now there are three things which alter the volume of air and other elastic fluids: 1. A change in the height of the barometer. 2. An increase or diminution of their quantity; the vessel in which they are contained remaining the same, and standing in the same quantity of water or mercury. 3. A change in the temperature of the air.

How to reduce air to a given barometrical pressure.

1. The density of air and other elastic fluids is always proportional to the compressing force. Now they are compressed by the weight of the atmosphere, which is measured by the barometer. If that weight diminishes, their density diminishes in proportion, and of course their bulk increases: if the weight of the atmosphere increases, their density increases, and their bulk diminishes in the same proportion. Consequently if the height of the barometer varies during an experiment, the bulk of the residuum will not be the same that it would have been if no such change had taken place.

* *Phil. Mag.* x. 56.

We will therefore commit an error unless we reduce the bulk of the residuum to what it would have been if no such alteration had taken place. This is easily done by a very simple formula.

It has been ascertained by philosophers, that the volumes of air are always inversely as the compressing forces. Therefore let m be the height of the barometer at the commencement of an experiment, n its height at the end; v the volume of the gas when the barometer is at n, and x its volume supposing the barometer at m. We have $n : m :: x : v$. Consequently $x = \frac{nv}{m}$.

So that to find the volume required, we have only to multiply the volume obtained by the actual height of the barometer, and divide by the height of the barometer at which we want to know the volume: And, in general, to reduce a volume of air to the volume it would occupy, supposing the barometer at 30 inches, we have only to use the above formula, substituting 30 in place of m.

To reduce it to the density of external air.

2. When air is confined in a jar standing over water or mercury, its density is not the same with that of the atmosphere, unless its lower surface in the jar be exactly level with the surface of the liquid in the tub in which it stands. Let A (fig. 39.) be a jar containing air, and BC the surface of the water or mercury in the tub in which the jar is inverted; the air within the jar is not of the same density with the external air, unless it fills exactly that part of the jar above BC. If it fill only that part of it between A and D while the water or mercury rises to D, the air will be more dilated than the external air, because it is compressed only by the weight of the atmosphere, diminished by the column of

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mercury or water D m. On the other hand, if the water or mercury only rise in the jar to E, the air within it will be denser than the external, because it is compressed by the weight of the atmosphere, and also by the column of water or air mE. It is proper therefore, in all cases, to bring the lower surface of the air in the jar to the same level with the surface of the water or mercury in the trough. But in eudiometrical experiments this is often impossible; because part of the air being absorbed, though the water or mercury over which it stands at first only rose to m, yet the absorption which takes place occasions it to rise to some line D above m. Hence the air which remains after the experiment is in a state of dilatation, and must be reduced by calculation to the volume which it would occupy were it in the same state of compression as at the commencement of the experiment. This is easily done by the following formula.

Let us suppose the experiment is made over mercury. Let H be the height of the barometer at the commencement of the experiment, h the length of the column of mercury mD, v the volume of the air in AD, and x the volume required, or the volume which the air would have supposing D to coincide with m. Then we have $H : H - h :: v : x$. And $x = \frac{(H-h)v}{H}$. Thus let H be 30 inches, $h = 5$ inches, and $v = 200$ cubic inches; then $x = 166\frac{2}{3}$ cubic inches; so that without this correction the error would amount to no less than $33\frac{1}{3}$ cubic inches, or about the sixth part of the whole. When the experiment is made over water, the same formula applies; only in that case H must be multiplied by 13.6. because a column of water 13.6 times

longer than mercury is necessary to produce the same pressure. In that case, supposing the numbers the same as before, x would be $= 197\frac{1}{2}$; so that the error over water is only $2\frac{1}{2}$ inches, or the 80th part of the whole.

Allowance for temperature.

3. A change in the temperature may be more easily guarded against in eudiometrical experiments, as they are usually made within doors: but when it does happen, it occasions an alteration in the volume of the air; an increase of temperature dilating it, and a diminution of temperature occasioning a condensation. This error may be easily corrected in air and all other gases, by increasing or diminishing their apparent bulk for every degree of change in the thermometer, according to the Table of the dilations of the gases formerly given *.

Composition of air.

We may consider it as established by experiment, that air is composed of 0.22 of oxygen gas and 0.78 of azotic gas by bulk. But as the weight of these two gases is not exactly the same, the proportion of the component parts by weight will differ a little: For as the specific gravity of oxygen gas is to that of azotic gas as 135 : 115, it follows that 100 parts of air are composed by weight of about

74	azotic gas
26	oxygen gas
100	

which differs very little from the determination of Lavoisier, provided that philosopher meant to denote by his numbers the weight and not the volume of the component parts of air.

* Volume I. p. 342.

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Air a chemical compound.

7. Having thus ascertained the nature and the proportion of the component parts of air, it remains only to enquire in what manner these component parts are united. Are they merely mixed together mechanically, or are they combined chemically? Is air a mechanical mixture or a chemical compound? Philosophers seem at first to have adopted the former of these opinions, if we except Scheele, who always considered air as a chemical compound. But Scheele's opinion gradually gained ground, in consequence chiefly of the experiments and observations of Morozzo, Humbolt, Berthollet, Davy, &c.; and had been adopted by most chemists when Mr Dalton's essay on the *Constitution of Mixed Gases, and particularly of the Atmosphere*, appeared in 1802 *. This excellent philosopher, distinguished by the simplicity and decisiveness of his experiments, and the happy talent of deducing from them general and important principles, formed a hypothesis altogether new. It has been long known that the density of elastic fluids is proportional to the compressing force; and from this it has been demonstrated, that their particles repel one another with a force reciprocally proportional to the distance of their centres from each other. Mr Dalton supposes that this property belongs only to *homogeneous* elastic fluids; that when two or more different elastic fluids are mixed together, the particles of the one neither attract nor repel the particles of the others; and of course that the mutual actions of such fluids are subject to the laws of inelastic bodies. By this hypothesis he explains, in a very satisfactory manner, seve-

* *Manchester Memoirs*, v. 535.

ral phenomena which had puzzled other philosophers; such as the uniform distribution and permanent mixture of two gases, notwithstanding the difference of their specific gravities.

Mr Dalton has adduced no other proof of the truth of this very ingenious hypothesis, except its exact correspondence with the phenomena. Several of these it accounts for remarkably well; but there are others scarcely reconcilcable to it. Thus it is well known that if a jar filled with hydrogen gas be kept with its mouth downwards, the gas continues for a considerable time almost pure; but if the mouth be turned up, the hydrogen gas vanishes, and common air takes its place almost in an instant. Now were Mr Dalton's hypothesis true, the hydrogen gas and common air ought to have mixed precisely in the same manner, and with the same rapidity, whatever was the position of the mouth of the jar. Exactly the opposite happens if the jar be filled with carbonic acid. When the mouth is uppermost, the jar remains full of carbonic acid for a considerable time; but when the mouth is inverted, the gas falls down, and common air takes its place in an instant. Nor is this owing to the mixture of the two airs; for the gas falls down nearly pure, as is evident from its effects on animals and burning bodies placed in its way. Many similar phenomena will readily occur to the practical chemist; all of which concur to show a tendency in the different gases to arrange themselves according to their specific gravities. But if Mr Dalton's hypothesis were true, I do not see how any such tendency could exist. There are many phenomena which render it probable that the different gases, when mixed together, really attract each other. Sulphurous acid

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and ammoniacal gas are absorbed instantaneously when brought into contact with water; but if they be mixed with a very small portion of air, the absorption is rendered very slow; and if a small portion of either of these gases be mixed with a large portion of air, water is incapable of absorbing them completely, unless it be agitated through the mixture. In like manner, lime-water, as Mr Cavendish has shown, is incapable of separating carbonic acid completely from air, even when agitated through it. Many other instances of similar attractions might easily be adduced. Now till these phenomena be shown to be consistent with Mr Dalton's very ingenious hypothesis, I do not see how it can be admitted.

But our object at present is to consider the hypothesis only so far as it relates to common air. Mr Dalton considers the atmosphere as a mixture of oxygen gas, azotic gas, carbonic acid, and vapour, totally unconnected with each other, and not acting upon each other. According to this hypothesis, there is no such substance, strictly speaking, as *air*; the term is synonymous with *atmosphere*, and signifies a collection of four or more gaseous bodies mechanically mixed. But the following reasons induce me, with the majority of chemists, to consider the oxygen and azote of the atmosphere as chemically combined, constituting a compound gas to which the term *air* has been appropriated. 1. It has been ascertained by eudiometrical trials in different countries, that the proportions of azote and oxygen in air are constant. Now as many causes continually operate to diminish the oxygen of the air, and as these causes act unequally in different places, it is difficult to conceive how this equality could subsist unless air be

a chemical compound. 2. Air, as has been shown by Morozzo and Humbolt, possesses properties which distinguish it from a mere mixture of its two component parts. The artificial mixture is much more diminished by nitrous gas than air, even when the mixture contains less oxygen *. It supports flame better and longer, and animals do not live in it the same time that they do in an equal portion of air, but longer †. 3. Different combustible bodies are capable of absorbing different portions of oxygen from a given quantity of air. Thus phosphorus absorbs 22 *per cent.* sulphur only 8 *per cent.* and gold no perceptible quantity. Now this is analogous to what happens to all other compounds containing oxygen. 4. A gas no way distinguishable from common air frequently makes its appearance during the preparation of nitric acid; and Mr Davy decomposed nitrous oxide by passing it through a red hot tube, and converted it into nitric acid, and a gas which possessed the properties of common air ‡. Now if air were a mere mixture, it is infinitely improbable that its two constituent parts should be evolved during such processes exactly in the proportion that exists in common air.

We must therefore consider air as a chemical compound. Hence the reason that it is in all cases the same, notwithstanding the numerous decomposing processes to which it is subjected. The breathing of animals, combustion, and a thousand other operations, are constantly abstracting its oxygen, and decomposing it.

* Humbolt, *Ann. de Chim.* xxviii. 162.

† Morozzo, *Jour. de Phys.* xlvii. 203.

‡ Davy's *Researches*, p. 279.

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The air thus decomposed or vitiated no doubt ascends in the atmosphere, and is again, by some unknown process or other, reconverted into atmospherical air. But the nature of these changes is at present concealed under an impenetrable veil.

SECT. II.

OF WATER.

Water of the atmosphere.

THAT the atmosphere contains water, has been always known. The rain and dew which so often precipitate from it, the clouds and fogs with which it is often obscured, and which deposite moisture on all bodies exposed to them, have demonstrated its existence in every age. Even when the atmosphere is perfectly transparent, water may be extracted from it in abundance by certain substances. Thus if concentrated sulphuric acid be exposed to air, it gradually attracts so much moisture, that its weight is increased more than three times: it is converted into diluted acid, from which the water may be separated by distillation. Substances which have the property of abstracting water from the atmosphere have received the epithet of *hygroscopic*, because they point out the presence of that water. Sulphuric acid, the fixed alkalies, muriat of lime, nitrat of lime, and in general all deliquescent salts, possess this property. The greater number of animal and vegetable bodies likewise possess it. Many of them take water from moist air, but give it out again to the air when

dry. These bodies augment in bulk when they receive moisture, and diminish again when they part with it. Hence some of them have been employed as *hygrometers* or measurers of the quantity of moisture contained in the air around them. This they do by means of the increase or diminution of their length, occasioned by the addition or abstraction of moisture. This change of length is precisely marked by means of an index. The most ingenious and accurate hygrometers are those of Saussure and Deluc. In the first, the substance employed to mark the moisture is a human hair, which by its contractions and dilatations is made to turn round an index. In the second, instead of a hair, a very fine thin slip of whalebone is employed. The scale is divided into 100°. The beginning of the scale indicates extreme dryness, the end of it indicates extreme moisture. It is graduated by placing it first in air made as dry as possible by means of salts, and afterwards in air saturated with moisture. This gives the extremes of the scale, and the interval between them is divided into 100 equal parts.

Detected by the hygrometer.

Since it cannot be doubted that the atmosphere always contains water, there are only two points which remain to be investigated: 1. The state in which that water exists in air; 2. The quantity which a given bulk contains.

I. With respect to the state in which water exists in air, two opinions have been formed, each of which has been supported by very able philosophers. 1. Water may be dissolved in air in the same manner as a salt is held in solution by water. 2. It may be mixed with air in the state of steam or vapour, after having been converted into vapour.

State in which water exists in air.

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1. The first of these opinions was hinted at by Dr Hooke in his *Micrographia*, and afterwards proposed by Dr Halley; but it was much more fully developed by Mr Le Roy of Montpelier in 1751. Dr Hamilton of Dublin made known the same theory about the same time. The phenomena in general coincide remarkably well with this theory. The quantity of water which air is capable of holding in solution is increased by every augmentation of temperature, and diminished by cold, which is precisely analogous to almost all other solvents. These analogies, and several others which will easily suggest themselves to the reader, have induced by far the greater number of philosophers to adopt this opinion.

2. The second theory; namely, that water exists in air in the state of vapour, has been embraced by Deluc in his last Treatise on Meteorology; at least his reasoning appears to me to lead to that conclusion. But it is to Mr Dalton that we are indebted for the most precise information on the subject *. The following reasons put the truth of this opinion almost beyond the reach of controversy.

It is in the state of vapour.

In the *first* place, It cannot be doubted that the water which exists in air, is derived originally from the waters on the surface of the earth, which are exposed to the action of the atmosphere. Accordingly we find that water, when exposed to the air, suffers a gradual diminution of bulk, and at last disappears altogether. This diminution of the water may be owing, either to its gradual solution in air, or to its conversion into

* *Manchester Memoirs*, v. p. 571.

vapour. The last is the common opinion, as the phenomenon is in common language ascribed to the *evaporation* of the water. When water is placed in an exhausted receiver, it diminishes in bulk even more rapidly than in the open air. In this case, as no air is present, we can only ascribe the diminution of bulk to the conversion of the water into vapour. Accordingly we find upon examination, that the receiver is actually filled with water in the state of vapour. The presence of this vapour very soon, by its elasticity, puts an end to the evaporation of the water. Now, since water disappears equally whether air be present or not, and exactly in the same manner, it is reasonable to ascribe its disappearing in both cases to the same cause But in the exhausted receiver it is converted into vapour. Hence it is probable that it is converted into vapour also in the open air; and if so, it must exist in air in the state of vapour.

In the *second* place, If the disappearing of water exposed to the open air were owing to solution and not to evaporation, it ought certainly to disappear more rapidly when it is exposed to the action of a great quantity of air than when to a small quantity; for the quantity of any body dissolved is always proportional to the quantity of the solvent. But the very contrary is what actually takes place with respect to the water contained in the air. Saussure has proved that water evaporates much faster at great heights than at the surface of the earth, even when the temperature and the moisture of the air in both places are the same. By comparing a set of experiments made upon the Col-du-Geant, at the height of 11,275 feet above the level of the sea, with a

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similar set made at Geneva 1324 feet above the level of the sea, he ascertained, that supposing the temperature and the dryness of the air in both places the same, the quantity of water evaporated at Geneva is to that evaporated on the Col-du-Geant in the same time and same circumstances as 37 to 84, or nearly as 3 : 7. Now the air on the Col-du-Geant is about $\frac{1}{3}$d rarer than at Geneva; so that a diminution of about $\frac{1}{3}$d in the density of the air more than doubles the rate of evaporation *. This is precisely what ought to be the case, provided the water which disappears mixes with the air in the state of vapour only; but the very contrary ought to hold, if the water disappeared in consequence of the solvent power of air.

In the *third* place, It has been demonstrated by Dr Black that vapour is water combined with a certain dose of caloric. Consequently when water is converted into vapour, a certain portion of caloric combines with it and disappears. If, therefore, there is the same waste of caloric whenever water passes from a liquid state and enters into the atmosphere as a component part, we have reason to conclude that it enters into the atmosphere only in the state of vapour. But it is a well known fact, that cold is always generated during spontaneous evaporation; that is to say, that the water as it disappears carries off with it a quantity of caloric. It is well known, that when a wet body is exposed to the air, its temperature is lowered by the evaporation which takes place upon its surface. Hence in warm countries water is cooled by putting it into porous vessels, and

* Saussure's *Voyages dans les Alpes*, iv. 263.

exposing it to the air. The water penetrates through the vessels, evaporates from their surface, and carries off so much heat, as even in some cases to freeze the water in the vessel. Saussure observed that the evaporation from the surface of melting snow caused it to freeze again when the temperature of the surrounding air was 4.5° above the freezing point. Dr Black has rendered it probable that the quantity of caloric which disappears during spontaneous evaporation, is as great as that which is necessary to convert water into steam. We have a right then to conclude, that water, when it evaporates spontaneously, is always converted into vapour, and of course that it is only in that state that it enters into the atmosphere.

In the *fourth* place, Mr Dalton has demonstrated, that the water which exists in air, possesses precisely the same degree of elasticity that it does when in the state of vapour in a vacuum at the same temperature. Hence it follows irresistibly that it exists in air, not in the state of water, but of an elastic fluid or vapour.

There may, indeed, be a small portion held in solution by air in the state of water; but this portion must be too minute to be perceptible. We know, at least, that water is capable of dissolving air, and that it always holds a portion of it in solution. It has been ascertained, that the affinity by which air is retained by water is so great, that several hours boiling are scarcely sufficient to separate it completely. Now, if water be capable of dissolving air, why may not air be capable also of dissolving water? And if so, it is reasonable to suppose that air always holds some water in solution in the state of water. But as water dissolves only a very small portion of air, and as air is a much rarer fluid than wa-

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ter, it is reasonable to conclude that it will dissolve proportionably less. But if this supposition be allowed, the quantity of water held in solution in air, in the state of water, must be very minute.

State of the vapour in the atmosphere.

We are authorized to conclude, then, that almost the whole of the water which exists in the atmosphere is in the state of vapour. But is this vapour chemically combined with air, or merely mechanically mixed with it? The first of these opinions was supported by Saussaure; but the late experiments of Dalton have rendered the last much more probable than I formerly thought it. This excellent philosopher has shewn, that when vapour is admitted to any gas, the gas experiences an expansion which is in all cases proportional to the elasticity of the vapour in that temperature. Let 1 represent the space occupied by any kind of gas of a given temperature, and free from moisture; p, the given pressure upon it in inches of mercury; f, the force of vapour from any liquid at that temperature in a vacuum: then the liquid being admitted to the air, an expansion ensues, and the space occupied by the air becomes $= 1 + \frac{f}{p-f}$, or (which is the same thing) $= \frac{p}{p-f}$. Thus let the temperature be 180°, $p = 30$ inches, and let the liquid be water; then $f = 15$ inches*. Then $\frac{p}{p-f} = \frac{30}{30-15} = 2$. So that the bulk of the air in this case is doubeld†. Now this law could scarcely be concei-

Effect of vapour on the bulk of air.

* Mr Dalton's Table of the force of vapour at different temperatures has been given in Vol. I. p. 370. of this Work.

† *Manchester Memoirs*, v. 572.

ved to hold in all cases, if vapour were chemically combined with air. But if it be mixed only mechanically, we must have recourse to Mr Dalton's peculiar hypothesis, to explain the reason why it is not condensed into water by the pressure of the air; and suppose, of course, that the particles of vapours are not repelled by those of air.

The truth is, that the subject is still involved in considerable obscurity. Many chemical phenomena shew a striking attraction between water and air. These phenomena have induced some philosophers to go so far as to suppose that water is a constituent part of air; and that therefore it cannot be wholly abstracted without destroying the air altogether, or depriving it of its elastic state. This opinion has been adopted by Dr Priestley in particular; and that philosopher has founded on it the objections which he has urged against the composition of water. The experiments of Mr Henry upon carbureted hydrogen gas have demonstrated, that air, even after it has been exposed to the action of the driest salts, and those which have the strongest affinity for moisture, still retains a portion of water. Mr Henry has pointed out a way of freeing some of the gases altogether from water by the action of electricity. When they are thus completely purified from water, they continue to retain their elastic form as much as ever. We may conclude, then, that air always contains water, but that water is not an ingredient so essential as to be necessary to the very existence of air in an elastic form; though a certain portion of it seems essential to render air fit to answer the different purposes for which it is intended; very dry air having excessingly

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unpleasant effects upon the animal economy, as has been remarked by Saussure and other philosophers.

Quantity of vapour in air.

II. Many attempts had been made to measure the quantity of water contained in air; but Saussure was the first who attained any thing like precision. This ingenious philosopher has shewn, in his Hygrometrical Essays, that an English cubic foot of air, when saturated with water at the temperature of 66°, contains only about 8 grains troy of that liquid, or about $\frac{1}{8}\frac{1}{7}$th of its weight. But the experiments of Mr Dalton were susceptible of more precision, and are therefore more to be depended on. As the greatest part of the water of the atmosphere is in the state of vapour, the elasticity of which depends upon the temperature, it is obvious that this elasticity, provided it can be ascertained, must measure the quantity of vapour which exists in the atmosphere, the temperature being the same. The elasticity or force of vapour is determined by this ingenious philosopher in the following manner: He takes a tall cylindrical glass jar, dry on the outside, and fills it with cold spring water fresh from the well; if dew be immediately formed on the outside, he pours the water out, lets it stand a while to increase in heat, dries the outside of the glass well with a linen cloth, and then pours the water in again. This operation is to be continued till the dew ceases to be formed, and then the temperature of the water must be observed; and opposite to it in the Table* will be found the force of vapour in the atmosphere. This must be done in the open air, or at a window; because the air within is ge-

Dalton's method of ascertaining its elasticity.

* Vol. I. p. 370.

nerally more humid than that without. Spring water is generally about 50°, and will mostly answer the purpose of the three hottest months in the year: in other seasons an artificial cold mixture is required. "The accuracy of the result obtained this way (says Mr Dalton) I think scarcely needs to be insisted upon. Glass, and all other hard smooth substances I have tried, when cooled to a degree below what the surrounding aqueous vapour can support, cause it to be condensed on their surfaces into water. The degree of cold is usually from 1 to 10 below the mean heat of the 24 hours; in summer I have often observed the point as high as 58° or 59°, corresponding to half an inch of mercury in force, and once or twice have seen it at 62°: in changeable and windy weather it is liable to considerable fluctuation; but this is not the place to enlarge upon it."

From his experiments it follows, that the quantity of vapour in the atmosphere is variable in quantity. In the torrid zone its force varies from 0 6 to 1 inch of mercury. In Britain it seldom amounts to 0.6, but is often as great as 0.5 during summer. In winter it is often as low as 0.1 of an inch of mercury *.

These facts would enable us to ascertain the absolute quantity of vapour contained in the atmosphere at any given time, provided we were certain that the density and elasticity of vapours follow precisely the same law as that of gases, as is extremely likely to be the case. If so, the vapour will vary from $\frac{1}{30}$th to $\frac{1}{150}$th part of the atmosphere.

* Dalton, *Manchester Memoirs*, v. 547.

SECT. III.

OF CARBONIC ACID GAS.

The existence of carbonic acid gas as a constituent part of the atmosphere, was observed by Dr Black immediately after he had ascertained the nature of that peculiar fluid. If we expose a pure alkali or alkaline earth to the atmosphere, it is gradually converted into a carbonat by the absorption of carbonic acid gas. This fact, which had been long known, rendered the inference that carbonic acid gas existed in the atmosphere unavoidable, as soon as the difference between a pure alkali and its carbonat had been ascertained to depend upon that acid. Not only alkalies and alkaline earths absorb carbonic acid when exposed to the air, but several of the metallic oxides also. Hence the reason that we so often find the native oxides in the state of carbonats. Thus *rust* is always saturated with carbonic acid.

Found at great heights.

Carbonic acid gas not only forms a constituent part of the atmosphere near the surface of the earth, but at the greatest heights which the industry of man has been able to penetrate. Saussure found it at the top of Mount Blanc, the highest point of the old continent; a point covered with eternal snow, and not exposed to the influence of vegetables or animals. Lime water diluted with its own weight of distilled water, formed a pellicle on its surface after an hour and three quarters exposure to the open air on that mountain; and slips of paper

moistened with pure potass, acquired the property of effervescing with acids after being exposed an hour and a half in the same place *. Now this was at a height no less than 15,668 feet above the level of the sea. Humbolt has more lately ascertained the existence of this gas in air, brought by Mr Garnerin from a height not less than 4280 feet above the surface of the earth, to which height he had risen in an air balloon†. This fact is a sufficient proof that the presence of carbonic acid in air does not depend upon the vicinity of the earth.

Its quantity.

The difficulty of separating this gas from air has hitherto prevented the possibility of determining with accuracy the relative quantity of it in a given bulk of air; but from the experiments which have been made, we may conclude, with some degree of confidence, that it is not very different from 0.01. From the experiments of Humbolt, it appears to vary from 0.005 to 0.01. This variation will by no means appear improbable, if we consider that immense quantities of carbonic acid gas must be constantly mixing with the atmosphere, as it is formed by the respiration of animals, by combustion, and several other processes which are going on continually. The quantity, indeed, which is daily formed by these processes is so great, that at first sight it appears astonishing that it does not increase rapidly. The consequence of such an increase would be fatal, as air containing 0.1 of carbonic acid extinguishes light, and is noxious to animals. But we shall find reason

* Saussure's *Voyages*, iv. 199.

† *Jour. de Phys.* xlvii. 202.

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afterwards to conclude, that this gas is decomposed by vegetables as rapidly as it forms.

On the supposition that the carbonic acid gas contained in a given bulk of air amounts to 0.01, the absolute quantity of it in the atmosphere would amount to somewhat more than 119,111,632,272,581,818 lbs. avoirdupois: an enormous quantity, which undoubtedly serves some valuable purpose in the atmosphere, though our knowledge of the changes which go on in that great laboratory is at present too imperfect to enable us even to conjecture the uses to which it may be applied.

SECT. IV.

OF THE OTHER BODIES FOUND IN THE ATMOSPHERE.

Composition of the atmosphere.

FROM the three preceding Sections we see that the atmosphere consists chiefly of three distinct elastic fluids united together by chemical affinity; namely, air, vapour, and carbonic acid gas; differing in their proportions at different times and in different places; but that the average proportion of each is

98 air
1 carbonic acid
1 water

100

Other bodies contained in it.

But besides these bodies which may be considered as the constituent parts of the atmosphere, the existence of several other bodies has been suspected in it. I do not

mean in this place to include among those bodies electric matter, or the substance of clouds and fogs, and those other bodies which are considered as the active agents in the phenomena of meteorology, but to confine myself merely to those foreign bodies which have been occasionally found or suspected in air. Concerning these bodies, however, very little satisfactory is known at present, as we are not in possession of instruments sufficiently delicate to ascertain their presence. We can indeed detect several of them actually mixing with air, but what becomes of them afterwards we are unable to say.

Hydrogen gas.

1. Hydrogen gas is said to have been found in air situated near the crater of volcanoes, and it is very possible that it may exist always in a very small proportion in the atmosphere; but this cannot be ascertained till some method of detecting the presence of hydrogen combined with a great proportion of air be discovered.

2. Carbureted hydrogen gas is often emitted by marshes in considerable quantities during hot weather. But its presence has never been detected in air; so that in all probability it is again decomposed by some unknown process.

3. Oxygen gas is emitted abundantly by plants during the day. We shall afterwards find reason to conclude that this is in consequence of the property which plants have of absorbing and decomposing carbonic acid gas. Now as this carbonic acid is formed at the expence of the oxygen of the atmosphere, as this oxygen is again restored to the air by the decomposition of the acid, and as the nature of atmospheric air remains unaltered, it is clear that there must be an equilibrium between these two processes; that is to say, all the carbo-

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nic acid formed by combustion must be again decomposed, and all the oxygen abstracted must be again restored. The oxygen gas which is thus continually returning to the air, by combining with it, makes its component parts always to continue in the same ratio.

4. The smoke and other bodies which are continually carried into the air by evaporation, &c. are probably soon deposited again, and cannot therefore be considered with propriety as forming parts of the atmosphere. But there is another set of bodies which are occasionally combined with air, and which, on account of the powerful action which they produce on the human body, have attracted a great deal of attention. These are known by the name of matters of *contagion*.

That there is a difference between the atmosphere in different places, as far as respects its effects upon the human body, has been considered as an established point in all ages. Hence some places have been celebrated as healthy, and others avoided as pernicious, to the human constitution. It is well known that in pits and mines the air is often in such a state as to suffocate almost instantaneously those who attempt to breathe it. Some places are haunted by peculiar diseases. It is known that those who frequent the apartments of persons ill of certain maladies, are extremely apt to catch the infection; and in prisons and other places, where crowds of people are confined together, when diseases once commence, they are wont to make dreadful havoc. In all these cases it has been supposed that a certain noxious matter is dissolved by the air, and that it is the action of this matter which produces the mischief.

This noxious matter is in many cases readily distin-

Contagious matter,

guished by the peculiarly disagreeable smell which it communicates to the air. No doubt this matter differs according to the diseases which it communicates, and the substance from which it has originated. Morveau lately attempted to ascertain its nature; but he soon found the chemical tests hitherto discovered altogether insufficient for that purpose. He has put it beyond a doubt, however, that the noxious matter which rises from putrid bodies, is of a compound nature, and that it is destroyed altogether by certain agents, particularly by those gaseous bodies which readily part with their oxygen. He exposed air infected by putrid bodies to the action of various substances; and he judged of the result by the effect which these bodies had in destroying the fetid smell of the air. The following is the result of his experiments.

How destroyed.

1. Odorous bodies, such as benzoin, aromatic plants, &c. have no effect whatever. 2. Neither have the solutions of myrrh, benzoin, &c. in alcohol, though agitated in infected air. 3. Pyrolignous acid is equally inert. 4. Gunpowder, when fired in infected air, displaces a portion of it; but what remains still retains its fetid odour. 5. Sulphuric acid has no effect; sulphurous acid weakens the odour, but does not destroy it. 6. Vinegar diminishes the odour, but its action is slow and incomplete. 7. Acetic acid acts instantly, and destroys the fetid odour of infected air completely. 8. The fumes of nitric acid, first employed by Dr Carmichael Smith, are equally efficacious. 9. Muriatic acid gas, first pointed out as a proper agent by Morveau himself, is equally effectual. 10. But the most powerful agent is oxy-muriatic acid gas, first proposed by Mr Cruickshanks, and now employed with the

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greatest success in the British Navy and Military Hospitals.

Thus there are four substances which have the property of destroying contagious matter, and of purifying the air: but acetic acid cannot easily be obtained in sufficient quantity, and in a state of sufficient concentration to be employed with advantage. Nitric acid is attended with inconvenience, because it is almost always contaminated with nitrous gas. Muriatic acid and oxymuriatic acid are not attended with these inconveniences; the last deserves the preference, because it acts with greater energy and rapidity. All that is necessary is to mix together two parts of common salt with one part of the black oxide of manganese, to place the mixture in an open vessel in the infected chamber, and to pour upon it two parts of sulphuric acid. The fumes of oxymuriatic acid are immediately exhaled, fill the chamber, and destroy the contagion.

CHAP. II.

OF METEOROLOGY.

THOUGH the phenomena of the weather must have at all times attracted much of the attention of mankind, because their subsistence and their comfort in a great measure depended upon them, it was not till the 17th century that any considerable progress was made in investigating the laws of meteorology. How desirous soever the ancients might have been to acquire an accurate knowledge of this science, their want of proper instruments entirely precluded them from cultivating it. By the discovery of the barometer and thermometer in the 17th century, and the invention of accurate electrometers and hygrometers in the 18th, this defect is now pretty well supplied; and philosophers are enabled to make meteorological observations with ease and accuracy. Accordingly a very great number of such observations have been collected, which have been arranged and examined from time to time by ingenious men, and consequences deduced from them, on which several different theories of the weather have been built. But meteorology is a science so exceedingly difficult, that, notwithstanding the united exertions of some of the first philosophers of the age, the phenomena of the weather are still very far from being completely under-

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stood; nor can we expect to see the veil removed till accurate tables of observations have been obtained from every part of the world, till the atmosphere has been more completely explored, and the chemical changes which take place in it ascertained.

The changes which take place in the atmosphere demonstrate, in the clearest manner, that new combinations and decompositions are continually going on in it. On these chemical alterations the greater number of meteorological phenomena depend: they may be considered as the result of the mutual action of the different component parts of the atmosphere; and would admit of an easy explanation, if we were thoroughly acquainted with all those substances, and with the chemical laws which govern their action. The most important meteorological phenomena are, 1. The changes which take place in the weight of the atmosphere; 2. The changes which take place in its temperature; 3. The changes in its quantity by evaporation and rain, &c.; 4. The violent agitation into which it is often thrown; and, 5. The electric and other phenomena which sometimes accompany or occasion these precipitations and agitations. The consideration of these subjects shall occupy the six following Sections.

SECT. I.

OF CHANGES IN THE WEIGHT OF THE ATMOSPHERE.

Height of the barometer on the sea shore.

We have seen in the last Chapter, that the barometer indicates to us the weight of a column of air, extending to the top of the atmosphere, and whose base is equal to that of the mercury. At the level of the sea, where the column of air is longest, the mean height of the barometer is 30 inches. This Sir George Shuckburgh found to be the case in the Mediterranean and the Channel, in the temperature of 55° and 60°; Mr Bouguer, on the coast of Peru, in the temperature of 84°; and Lord Mulgrave, in latitude 80°. The mean height of the barometer is less the higher any place is situated above the level of the sea, because the column of air which supports the mercury is the shorter. The barometer has accordingly been used for measuring heights. But if a barometer be allowed to remain in one place, the mercury does not continue stationary; sometimes it rises and at other times falls, varying to the extent of several inches; of course the weight of the air which balances the mercury must be subject to the same changes. Hence we learn that the air in the same place is sometimes light and at other times heavy; differences which must be owing to changes in its quantity. The barometer then informs us, that the quantity of air above any spot is liable to continual alterations. Consequently either the air accumulates in par-

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ticular spots, while it partially abandons others; of part of the atmosphere must be alternately abstracted altogether, and restored again by some constant though apparently irregular process.

Between the tropics the variations of the barometer are exceedingly small; and it is remarkable, that in that part of the world it does not descend above half as much for every 200 feet of elevation as it does beyond the tropics‖. In the torrid zone, too, the barometer is elevated about two thirds of a line twice every day; and this elevation happens at the same time with the tides of the sea¶.

Annual range.

As the latitude advances towards the poles, the range of the barometer gradually increases, till at last it amounts to two or three inches. This gradual increase will appear from the following TABLE.

TABLE *of the Range of the Barometer.*

Latitude.	Places.	Range of the Barometer.	
		Greatest.	Annual.
0°	Peru	0.20 *	—
22 23′	Calcutta	0.77 †	—
33 55	Cape Town	—	0.89 ‡
40 55	Naples	1.00 *	—
51 8	Dover	2.47 §	1.80
53 13	Middlewick	3.00 §	1.94
53 23	Liverpool	2.89 §	1.96
59 56	Petersburgh	3.45 **	2.77

‖ M. Cassan, *Jour. d Phys.* April 1790, p. 268. ¶ Ibid.

* Kirwan, *Irish Trans.* vol. iii. p. 47.

† *Asiatic Researches*, vol. ii. Appendix.

‡ Barrow's *Travels*, p. 42. § *Manchester Trans.* vol. iv.

** *Edinburgh Trans.* vol. ii. p. 229.

In North America, however, the range of the barometer is a great deal less than in the corresponding European latitudes. In Virginia, for instance, it never exceeds 1.1 *.

The range of the barometer is greater at the level of the sea than on the mountains; and in the same degree of latitude, the extent of the range is in the inverse ratio of the height of the place above the level of the sea.

Diurnal range.

From a table published by Mr Cotte in the *Journal de Physique* †, it seems exceedingly probable that the barometer has always a tendency to rise from the morning to the evening; and that this tendency is greatest between two o'clock in the afternoon and nine at night, at which hour the greatest elevation takes place; that the elevation of nine o'clock differs from that of two by $\frac{4}{11}$ths, while that at two differs from the morning elevation only by $\frac{1}{11}$th; and that in certain climates the greatest elevation takes place at two o'clock. The following is a part of the Table on which these observations are founded, reduced to the English standard.

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* *Trans. Philadel.* vol. ii. p. 142. † Aug. 1790, p. 110.

Places.	Years of observation.	Mean Height of the Barometer.			
		Morning.	Noon.	Evening.	Year.
Arles	6	29.9347	29.9347	29.9413	29.9347
Arras	6	29.6683	29 6683	29 6832	29.6758
Bourdeaux	11	29.7212	29.8385	29.8385	29.8385
Cambray	13	29.8756	29.8682	29.8756	29.8756
Chinon	12	29.7719	29.7795	29 8001	29.7869
Dunkirk	8	29.9199	29.9347	29 9347	29.9273
Hagenau	10	29.5648	29,5648	29.5741	29.5648
Laon	7	29.3354	29.3206	29.3429	29.3354
Lisle	6	29.9165	29.9274	29.9347	29.9077
Mayenne	7	29.7172	29.7056	29.7127	29.7127
Manheim	5	29.6167	29.6018	29.6167	29.6093
Montmorenci	22	29.6536	29.6536	29.6610	29.6536
Mulhausen	7	29.1873	29.1800	29.1873	29.1873
Obernheim	12	29.4834	29.4665	29.4764	29.4764
Paris	67	29.8902	29.8607	29.8756	29.8756
Poitiers	12	29.7276	29.7276	29.7276	29.7276
Rouen	11	29.8607	29.8535	29.8535	29.8535
Rome	3	29.8607	29.8460	29.8756	29.8607
St Maurice le Gerard	10	29.8016	29.8016	29.8090	29.8016
Troyes	10	29.6885	29.6979	29 6885	29.6885

From the observations of Mr Luke Howard, as confirmed by Cotte, it appears that the barometer has a tendency to sink at new and full moon, and to rise at the quarters. This coincidence is greatest in calm and fair weather. The depression from the quarters to the conjunctions amounts to $\frac{1}{10}$ inch; and the elevation from the conjunctions to the quarters amounts to the same quantity.

The range of the barometer is greater in winter than in summer. Thus at York the mean range of the barometer, during October, November, December, Ja-

nuary, February, March, of the year 1774, was 1.42; and for the six summer months 1.016*.

In serene and settled weather it is generally high; and low in calm weather, when the air is inclined to rain; it sinks on high winds, rises highest on easterly and northerly winds, and sinks when the wind blows from the south†. At Calcutta ‡, it is always highest when the wind blows from the north-west and north, and lowest when it blows from the south-east.

The barometer falls suddenly before tempests, and undergoes great oscillations during their continuance. Mr Copland § of Dumfries has remarked, that a high barometer is attended with a temperature above, and a low barometer with one below, the monthly mean.

Such are the phenomena respecting the variations of the barometer, as far as they can be reduced under general heads. Various attempts have been made to explain them, but hitherto without any great degree of success. The theory of Mr Kirwan appears to me by far the most plausible, though it is not sufficient to explain all the facts. The following observations may be considered as a kind of abstract of his theory, except in one or two instances.

Atmosphere highest at the equator.

It is evident that the density of the atmosphere is least at the equator and greatest at the poles; for at the equator the centrifugal force, the distance from the centre of the earth, and the heat, all of which tend to diminish the density of the air, are at their maximum, while at the pole they are at their minimum. The

* *Manchester Trans* vol. iv. p. 543. † Dr Halley.

‡ *Asiatic Researches*, vol. ii. Appendix.

§ *Manchester Trans.* vol. iv.

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mean height of the barometer at the level of the sea, all over the globe, is 30 inches; the weight of the atmosphere, therefore, is the same all over the globe. The weight of the atmosphere depends on its density and height: where the density of the atmosphere is greatest, its height must be least; and, on the contrary, where its density is least, its height must be the greatest. The height of the atmosphere, therefore, must be greatest at the equator, and least at the poles; and it must decrease gradually between the equator and the poles, so that its upper surface will resemble two inclined planes, meeting above the equator their highest part *.

During summer, when the sun is in our hemisphere, the mean heat between the equator and the pole does not differ so much as in winter. Indeed the heat of northern countries at that time equals the heat of the torrid zone: thus in Russia, during July and August, the thermometer rises to 85° †. Hence the rarity of the atmosphere at the pole, and consequently its height, will be increased. The upper surface of the atmosphere, therefore, in the northern hemisphere will be less inclined, while that of the southern hemisphere, from contrary causes, will be much more inclined. The very reverse will take place during our winter.

The density of the atmosphere depends in a great measure on the pressure of the superincumbent column; and therefore decreases, according to the height, as the pressure of the superincumbent column constantly decreases. But the density of the atmosphere in the torrid zone will not decrease so fast as in the temperate and frigid zones; because its column is longer, and because

* Kirwan, *Irish Trans.* vol, ii. p. 43, &c.

† Dr Guthrie *Edin. Trans.* vol. ii. p. 229.

there is a greater proportion of air in the higher part of this column. This accounts for the observation of Mr Cassan, that the barometer only sinks half as much for every 200 feet of elevation in the torrid as in the temperate zones *. The density of the atmosphere at the equator, therefore, though at the surface of the earth it is less, must at a certain height equal, and at a still greater surpass, the density of the atmosphere in the temperate zones and at the poles.

Hence the air, as it ascends, rolls towards the coldest pole.

A current of air is constantly ascending at the equator, and part of it at least reaches and continues in the higher parts of the atmosphere. From the fluidity of air, it is evident that it cannot accumulate above the equator, but must roll down the inclined plane which the upper surface of the atmosphere assumes towards the poles. As the surface of the atmosphere of the northern hemisphere is more inclined during our winter than that of the southern hemisphere, a greater quantity of the equatorial current of air must flow over upon the northern than upon the southern atmosphere; so that the quantity of our atmosphere will be greater during winter than that of the southern hemisphere: but during summer the very reverse will take place. Hence the greatest mercurial heights take place during winter, and the range of the barometer is less in summer than in winter.

Air accumulates over cold places.

The density of the atmosphere is in a great measure regulated by the heat of the place: wherever the cold is greatest, there the density of the atmosphere will be

* Should it not be examined whether the number of parts which the mercury sinks for every 200 feet of elevation be not proportioned to the latitude of the place?

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greatest, and its column shortest. High countries, and ranges of lofty mountains, the tops of which are covered with snow the greatest part of the year, must be much colder than other places situated in the same degree of latitude, and consequently the column of air over them much shorter. The current of superior air will linger and accumulate over these places in its passage towards the poles, and thus occasion an irregularity in its motion, which will produce a similar irregularity in the barometer. Such accumulations will be formed over the north-western parts of Asia and over North America: hence the barometer usually stands higher, and varies less there than in Europe. Accumulations are also formed upon the Pyrenees, the Alps, the mountains of Africa, Turkey in Europe, Tartary and Tibet. When these accumulations have gone on for some time, the density of the air becomes too great to be balanced by the surrounding atmosphere; it rushes down on the neighbouring countries, and produces cold winds which raise the barometer. Hence the rise of the barometer which generally attends north-east winds in Europe, as they proceed from accumulations in the north-west of Asia, or about the pole; hence, too, the north-west wind from the mountains of Tibet raises the barometer at Calcutta.

It is probable that considerable quantities of air are occasionally destroyed in the polar regions. When this happens, the atmosphere to the south rushes in to fill up the void. Hence south-west winds take place, and the barometer falls.

As the mean heat of our hemisphere differs in different years, the density of the atmosphere, and consequently the quantity of equatorial air which flows to-

wards the poles, must also be variable. Hence the range of the barometer is different in different years. Does this range correspond to the mean annual heat; that is to say, is the range greatest when the heat is least, and least when the heat is greatest? In some years greater accumulations than usual take place in the mountainous parts in the south of Europe and Asia, owing, perhaps, to earlier falls of snow, or to the rays of the sun having been excluded by long continued fogs. When this takes place, the atmosphere in the polar regions will be proportionably lighter. Hence the prevalence of southerly winds during some winters more than others.

Why the barometer varies little between the tropics.

As the heat in the torrid zone never differs much, the density, and consequently the height of the atmosphere, will not vary much. Hence the range of the barometer within the tropics is comparatively small; and it increases gradually as we approach the poles, because the difference of the temperature, and consequently of the density, of the atmosphere increases with the latitude.

The diurnal elevation of the barometer in the torrid zone corresponding to the tides, observed by Mr Cassan and others, must be owing to the influence of the moon on the atmosphere. This influence, notwithstanding the ingenious attempts of D'Alembert and several other philosophers, seems altogether inadequate to account for the various phenomena of the winds. It is not so easy to account for the tendency which the barometer has to rise as the day advances, which seems to be established by Mr Cotte's table. Perhaps it may be accounted for by the additional quantity of vapour added to the atmosphere, which, by increasing the

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quantity of the atmosphere, may possibly be adequate to produce the effect.

The falls of the barometer which precede, and the oscillations which accompany, violent storms and hurricanes, show us that these phenomena are produced by very great rarefactions, or perhaps destruction of air, in particular parts of the atmosphere. The falls of the barometer, too, that accompany winds, proceed from the same cause.

The falling of the barometer, which generally precedes rain, remains still to be accounted for; but we know too little about the causes by which rain is produced to be able to account for it in a satisfactory manner.

SECT. II.

OF THE TEMPERATURE OF THE ATMOSPHERE.

THAT the temperature of the air varies considerably, not only in different climates and in different seasons, but even in the same place and in the same season, must be obvious to the most careless observer. This perpetual variation cannot be ascribed to the direct heat of the sun; for the rays of that luminary seem to produce no effect whatever upon air though ever so much concentrated: but they warm the surface of the earth, which communicates its heat to the surrounding atmosphere. Hence it happens that the temperature of the air is highest in those places which are so situated as to

be most warmed by the sun's rays, and that it varies in every region with the season of the year. Hence too the reason why it diminishes according to the height of the air above the surface of the earth. That portion of the earth which lies at the equator is exposed to the most perpendicular rays of the sun. Of course it is hottest, and the heat of the earth diminishes gradually from the equator to the poles. The temperature of the air must follow the same order. The air, then, is hottest over the equator, and its temperature gradually diminishes from the equator to the poles, where it is coldest of all. It is hottest at the equator, and it becomes gradually colder according to its height above that surface. Let us examine the nature of these two diminishing progressions of temperature.

Method of ascertaining the mean annual temperature.

1. Though the temperature of the air is highest at the equator, and gradually sinks as it approaches the pole; yet as, in every place, the temperature of the air is constantly varying with the season of the year, we cannot form any precise notion of the progression without taking the temperature in every degree of latitude for every day of the year, and forming from each a mean temperature for the whole year; which is done by adding together the whole observations, and dividing by their number. The quotient gives the mean temperature for the year. The diminution from the pole to the equator takes place in arithmetical progression: or, to speak more properly, the annual temperature of all the latitudes are arithmetical means between the mean annual temperature of the equator and the pole. This was first discovered by Mr Mayer; and by means of an equation which he founded on it, but rendered considerably plainer and simpler, Mr Kirwan

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has calculated the mean annual temperature of every degree of latitude between the equator and the pole. He proceeded on the following principle: Let the mean annual heat at the equator be m, and at the pole $m - n$; put Φ for any other latitude; the mean annual temperature of that latitude will be $m - n \times \sin. \Phi^2$. If therefore the temperature of any two latitudes be known, the value of m and n may be found. Now the temperature of north lat. 40° has been found by the best observations to be 62.1°, and that of lat. 50°, 52.9°. The square of the sine of 40° is nearly 0.419, and the square of the sine of 50° is nearly 0.586. Therefore

$$m - 0.41\, n = 62.1, \text{ and}$$

$$m - 0.58\, n = 52.9; \text{ therefore}$$

$62.1 + 0.41\, n = 52.9 + 0.58\, n$, as each of them, from the two first equations, is equal to m. From this last equation the value of n is found to be 53 nearly; and m is nearly equal to 84. The mean temperature of the equator therefore is 84°, and that of the pole 31°. To find the mean temperature for every other latitude, we have only to find 88 arithmetical means between 84 and 31. In this manner Mr Kirwan calculated the following TABLE:

TABLE *of the Mean Annual Temperature of the Standard Situation in every Latitude.*

Lat.	Temper.	Lat.	Temper.	Lat.	Temper.	Lat.	Temper.
90	31.	68	38.4	46	56.4	24	75.4
89	31.04	67	39 1	45	57.5	23	75.9
88	31.10	66	39.7	44	58.4	22	76.5
87	31.14	65	40.4	43	59.4	21	77.2
86	31.2	64	41.2	42	60.3	20	77.8
85	31.4	63	41.9	41	61.2	19	78.3
84	31.5	62	42.7	40	62.	18	78.9
83	31.7	61	43.5	39	63.	17	79.4
82	32.	60	44.3	38	63.9	16	79.9
81	32.2	59	45.09	37	64.8	15	80.4
80	32.6	58	45.8	36	65.7	14	80.8
79	32.9	57	46.7	35	66.6	13	81.3
78	33.2	56	47.5	34	67.4	12	81.7
77	33.7	55	48.4	33	68.3	11	82.
76	34.1	54	49.2	32	69.1	10	82.3
75	34.5	53	50.2	31	69.9	9	82.7
74	35.	52	51.1	30	70.7	8	82.9
73	35.5	51	52.4	29	71.5	7	83.2
72	36.	50	52.9	28	72 3	6	83.4
71	36.6	49	53.8	27	72.8	5	83.6
70	37.2	48	54.7	26	73.8	0	84.
69	37.8	47	55.6	25	74.5		

This Table, however, only answers for the temperature of the atmosphere of the ocean. It was calculated for that part of the Atlantic Ocean which lies between the 80th degree of northern and the 45th of southern latitude, and extends westwards as far as the Gulf-stream, and to within a few leagues of the coast of America; and for all that part of the Pacific Ocean reaching from lat. 45° north to lat. 40° south, from the 20th to the 275th degree of longitude east of London. This part of the ocean Mr Kirwan calls the standard; the

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rest of the ocean is subject to anomalies which will be afterwards mentioned.

Mean monthly temperature.

Mr Kirwan has also calculated the mean monthly temperature of the standard ocean. The principles on which he went were these: The mean temperature of April seems to approach very nearly to the mean annual temperature; and as far as heat depends on the action of the solar rays, the mean heat of every month is as the mean altitude of the sun, or rather as the sine of the sun's altitude. The mean heat of April, therefore, and the sine of the sun's altitude being given, the mean heat of May is found in this manner: As the sine of the sun's mean altitude in April is to the mean heat of April, so is the sine of the sun's mean altitude in May to the mean heat of May. In the same manner the mean heats of June, July, and August, are found; but the rule would give the temperature of the succeeding months too low, because it does not take in the heat derived from the earth, which possesses a degree of heat nearly equal to the mean annual temperature. The real temperature of these months therefore must be looked upon as an arithmetical mean between the astronomical and terrestrial heats. Thus in latitude 51°, the astronomical heat of the month of September is 44.6°, and the mean annual heat is 52.4°; therefore the real heat of this month should be $\frac{44.6+52.4}{2}=48.5$. Mr Kirwan, however, after going through a tedious calculation, found the results to agree so ill with observations, that he drew up the following TABLE, partly from principles, and partly by studying a variety of sea journals.

TABLE *of the Monthly Mean Temperature of the Standard from Lat.* 80° *to Lat.* 10°.

Lat.	80°	79°	78°	77°	76°	75°	74°	73°	72°	71°	70°	69°	68°	67°	66°	65°	64°	63°
Jan.	22.	22.5	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.	27.5	27.5	28.	28.	28.	29.	30.
Feb.	23.	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.	27.5	28.	28.	28.5	29.	30.	31.	32.
March	27.	27.5	28.	28.5	29.	29.5	30.	30.5	31.	31.5	32.	32.5	33.	33.5	34.	35.	36.	37.
April	32.6	32.9	33.2	33.7	34.1	34.5	35.	35.5	36.	36.6	37.2	37.8	38.4	39.1	39.7	40.4	41.2	41.9
May	36.5	36.5	37.	37.5	38.	38.5	39.	39.5	40.	40.5	41.	41.5	42.	42.5	43.	44.	45.	46.
June	51.	51.	51.5	52.	52.	52.	52.5	53.	53.5	54.	54.	54.5	54.5	54.5	55.	55.	55.5	55.5
July	50.	50.	50.5	51.	51.	51.	51.5	52.	52.5	53.	53.5	53.5	53.5	54.	54.5	54.5	55.	55.
August	39.5	40.	41.	41.5	42.	42.5	43.	43.5	44.	44.5	45.	45.5	46.	47.	48.	48.5	49.	50.
Sept.	33.5	34.	34.5	35.	35.5	36.	36.5	37.	38.	38.5	39.	39.5	40.	41.	42.	43.	44.	45.
Octob.	28.5	29.	29.5	30.	30.5	31.	31.5	32.	32.5	33.	33.5	34.	34.	35.	36.	37.	37.5	38.
Nov.	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.	27.5	28.	28.5	29.	30.	31.	32.	32.5	33.
Dec.	22.5	23.	23.5	24.	24.5	25.	25.5	26.	26.5	27.	27.5	28.	28.	29.	30.	30.5	31.	31.

TABLE *of the Monthly Mean Temperature, &c. continued.*

Lat.	62°	61°	60°	59°	58°	57°	56°	55°	54°	53°	52°	51°	50°	49°	48°	47°	46°	45°
Jan.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	42.5	43.5	43.	42.5	44.	44.5
Feb.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	44.5	44.5	45.	45.5	46.	46.5
March	38.	39.	40.	41.	42.	43.	44 6	45.	46.	48.	49.	50.	50.5	51.	52.5	53.	53.5	54.5
April	42.7	43.5	44.3	45.09	45.8	46.7	47.5	48.4	49.2	50.2	51.1	52.4	52.9	53.8	54.7	55.6	56.4	57.5
May	47.	48.	49.	50.	51.	52.	53.	54.	55.	56.	57.	58.	58.5	59.	60.	61.	62.	63.
June	56.	56.	56.	56.5	57.	57.	57.5	58.	58.5	59.	59.	60.	61.	62.	63.	64.	65.	66.
July	55.5	55.5	56.	56.5	57.	57.5	58.	59.	60.	61.	62.	63.	63.5	64.	65.	66.	67.	68.
August	51.	52.	53.	54.	55.	56.	57.	58.	59.	60.	61.	62.	63.5	64.	65.	66.	67.	68.
Sept.	46.	47.	48.	49.	50.	51.	52.	53.	54.	55.	56.	57.	58.5	59.	60.	61.	62.	63.
Octob.	39.	40.	41.	42.	43.	44.	45.	46.	47.	48.	49.	50.	50.5	51.	52.	53.	54.	55.
Nov.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.5	46.	46.5	47.	48.	49.	50.	51.
Dec.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	44.	44.5	45.	46.	47.	48.	49.

TABLE *of the Monthly Mean Temperature, &c. continued.*

Lat.	44°	43°	42°	41°	40°	39°	38°	37°	36°	35°	34°	33°	32°	31°	30°	29°	28°	27°
Jan.	45.	45.5	46.	46.5	49.5	51.	52.	53.5	55.	56.5	59.5	63.	63.	63.	63.5	63.5	63.5	64.
Feb.	47.	48.	49.	50.	53.	56.5	58.	60.	61.	62.	63.	64.5	66.	67.	68.5	68.5	69.5	69.5
March	55.5	56.5	58.5	59.5	60.	60.5	61.	62.	63.	64.	65.	66.5	67.5	68.5	69.5	71.	72.	72.5
April	58.4	59.4	60.3	61.2	62.1	63.	63.9	64.8	65.7	66.6	67.4	68.3	69.1	69.9	70.7	71.5	72.3	72.8
May	64.	65.	66.	67.	68.	69.	70.	70.5	71.	71.5	72.	72.5	73.	73.	73.5	74.5	75.5	76.
June	67.	68.	69.	70.	70.5	71.	71.	71.	71.5	71.5	72.	72.5	73.	73.	73.5	74.5	75.5	76.
July	69.	69.5	70.	70.	71.	71.	72.	72.	72.5	72.5	72.5	72.5	73.	73.	73.5	74.5	75.5	76.
August	69.	69.5	70.	70.	71.	71.	72.	72.	72.5	72.5	72.5	72.5	73.	73.	73.5	74.5	75.5	76.
Sept.	64.	66.	68.	69.5	70.5	71.	71.5	72.	72.5	72.5	72.5	72.5	73.	73.	73.5	74.	75.5	76.
Octob.	56.	57.	58.	59.	60.	61.	62.	63.	64.	65.	66.	67.5	68.5	69.5	70.5	71.	72.5	72.5
Nov.	52.	53.	54.	55.	56.	57.	58	59.	60.	61.	62.	63.	64.5	65.5	66.5	68.	69.	69.5
Dec.	50.	51.	52.	53.	54.	55.	56.	57.	58.	59.	60.	61.	62.5	63.5	64.5	66.	67.	67.5

TABLE *of the Monthly Mean Temperature, &c. continued.*

Lat.	26°	25°	24°	23°	22°	21°	20°	19°	18°	17°	16°	15°	14°	13°	12°	11°	10°
Jan.	64.5	65.5	67.	68.	69.	71.	72.	72.5	73.	73.5	74.	74.5	75.	76.	76.5	77.	77.5
Feb.	70.5	71.	72.	72.	72.5	74.	75.	76.	76.5	77.	77.5	78.	78.5	79.	79.5	79.8	80.
March	73.	73.5	74.5	75.	75.5	76.	77.	77.5	78.	78.5	79.	79.5	80.	80.8	81.	81.5	81.8
April	73.8	74.5	75.4	75.9	76.5	77.2	77.8	78.3	78.9	79.4	79.9	80.4	80.8	81.3	81.7	82.	82.3
May	76.5	77.5	78.	78.5	79.5	80.	80.5	81.	81.5	82.	82.5	83.	83.	83.5	84.	84.	84.3
June	76.5	78.	78.5	79.	79.5	80.	80.5	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
July	76.5	78.	78.5	79.	79.5	80.	80.5	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
August	76.5	78.	78.5	79.	79.5	80.	80.5	81.5	82.	82.5	83.	83.5	83.8	84.	84.3	84.6	84.8
Sept.	76.5	77.5	78.	78.5	79.	79.5	80.	81.	81.5	82.	82.5	83.	83.	83.5	84.	84.3	84.6
Octob.	73.	73.5	74.5	75.	75.5	77.	78.	79.	80.	81.	81.5	82.	82.5	83.	83.5	83.8	84.
Nov.	71.5	72.	73.5	74.	74 5	75.	75.5	76.	77.	78.	78.5	79.	79.5	80.	80.5	80.8	81.
Dec.	68.5	69.5	70.	71.	71.5	72.	72.5	73.	74.	75.	75.5	76.	76.5	77.	77.5	78.	78.5

From this Table it appears that January is the coldest month in every latitude, and that July is the warmest month in all latitudes above 48°. In lower latitudes August is generally warmest. The difference between the hottest and coldest months increases in proportion to the distance from the equator. Every habitable latitude enjoys a mean heat of 60° for at least two months; this heat seems necessary for the production of corn. Within ten degrees of the poles, the temperatures differ very little, neither do they differ much within ten degrees of the equator; the temperatures of different years differ very little near the equator, but they differ more and more as the latitudes approach the poles.

Temperature diminishes with the height of the air.

2. That the temperature of the atmosphere gradually diminishes, according to its height above the level of the sea, is well known. Thus the late Dr Hutton of Edinburgh found that a thermometer, kept on the top of Arthur's seat, usually stood 3 degrees lower than a thermometer kept at the bottom of it. Hence then a height of 800 feet occasioned 3° of diminution of temperature. On the summit of Pinchinca the thermometer stood at 30°, as observed by Bouguer, while at the level of the sea in the same latitude it stood at 84°. Here a height of 15564 feet occasioned a diminution of temperature, amounting to 54°. But though there can be no doubt of the gradual diminution of temperature, according to the height, it is by no means easy to determine the rate of diminution. Euler supposes it to be in a harmonic progression; but this opinion is contradicted by observations. Saussure supposes, that in temperate climates the diminution of temperature amounts to 1° for every 287 feet of elevation. But Mr Kirwan has shewn that no such rule holds, and that the rate of diminution va-

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ries with the temperature at the surface of the earth. We are indebted to this philosopher for a very ingenious method of determining the rate of diminution in every particular case, supposing the temperature at the surface of the earth known *.

Since the temperature of the atmosphere is constantly diminishing as we ascend above the level of the sea, it is obvious, that at a certain height we arrive at the region of perpetual congelation. This region varies in height according to the latitude of the place; it is highest at the equator, and descends gradually nearer the earth as we approach the poles. It varies also according to the season, being highest in summer and lowest in winter. M. Bouguer found the cold on the top of Pinchinca, one of the Andes, to extend from seven to nine degrees below the freezing point every morning immediately before sun-rise. He concluded, therefore, that the mean height of the *term of congelation* (the place where it freezes during some part of the day all the year round) between the tropics was 15,577 feet above the level of the sea; but in lat. 28° he placed it in summer at the height of 13,440 feet. Now, if we take the difference between the temperature of the equator and the freezing point, it is evident that it will bear the same proportion to the term of congelation at the equator that the difference between the mean temperature of any other degree of latitude and the freezing point bears to the term of congelation in that latitude. Thus the mean heat of the equator being 84°, the difference between it and 32 is 52; the mean heat

* *Irish Trans.* viii. 356.

of latitude 28° is 72.3°, the difference between which and 32 is 40.3: Then 52: 15577 : : 40.3 : 12072. In this manner Mr Kirwan calculated the following Table:

Lat.	Mean height of the Term of Congelation. Feet.
0	15577
5	15457
10	15067
15	14498
20	13719
25	13030
30	11592
35	10664
40	9016
45	7658
50	6260
55	4912
60	3684
65	2516
70	1557
75	748
80	129

Beyond this height, which has been called the lower term of congelation, and which must vary with the season and other circumstances, Mr Bouguer has distinguished another, which he called the *upper* term of congelation; that is, the point above which no visible vapour ascends. Mr Kirwan considers this line as much less liable to vary during the summer months than the lower term of congelation, and therefore has made choice of it to determine the rate of the diminution of

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heat, as we ascend in the atmosphere. Bouguer determined the height of this term in a single case, and Kirwan has calculated the following Table of its height for every degree of latitude in the northern hemisphere *.

TABLE *of the Height of the Upper Line of Congelation in the different Latitudes of the Northern Hemisphere.*

N. Lat.	Feet.	N. Lat.	Feet.	N. Lat.	Feet.	N. Lat.	Feet.
0	28000	26	22906	48	12245	70	4413
5°	27784	27	22389	49	11750	71	4354
6	27644	28	21872	50	11253	72	4295
7	27504	29	21355	51	10124	73	4236
8	27364	30	20838	52	8965	74	4177
9	27224	31	20492	53	7806	75	4119
10	27084	32	20146	54	6647	76	4067
11	26880	33	19800	55	5617	77	4015
12	26676	34	19454	56	5533	78	3963
13	26472	35	19169	57	5439	79	3911
14	26268	36	18577	58	5345	80	3861
15	26061	37	17985	59	5251	81	3815
16	25781	38	17393	60	5148	82	3769
17	25501	39	16801	61	5068	83	3723
18	25221	40	16207	62	4989	84	3677
19	24941	41	15712	63	4910	85	3631
20	24661	42	15217	64	4831	86	3592
21	24404	43	14722	65	4752	87	3553
22	24147	44	14227	66	4684	88	3514
23	23890	45	13730	67	4616	89	3475
24	23633	46	13235	68	4548	90	3432
25	23423	47	12740	69	4480		

* For the method which Mr Kirwan followed in constructing this Table, the reader is referred to his *Estimate of the Temperature of different Climates*, and his Essay *On the Variation of the Atmosphere.*

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The following rule of Mr Kirwan will enable us to ascertain the temperature at any required height, provided we know the temperature at the surface of the earth.

How calculated.

Let the observed temperature at the surface of the earth be $= m$, the height given $= b$, and the height of the upper term of congelation for the given latitude be $= t$; then $\frac{m - 32}{\frac{t}{100} - 1}$ = the diminution of temperature for every hundred feet of elevation; or it is the common difference of the terms of the progression required. Let this common difference thus found be denoted by c; then $c \times \frac{b}{100}$ gives us the whole diminution of temperature from the surface of the earth to the given height. Let this diminution be denoted by d, then $m - d$ is obviously the temperature required. An example will make this rule sufficiently obvious. In latitude 56°, the heat below being 54°, required the temperature of the air at the height of 803 feet?

Here $m = 54$, $t = 5533$, $\frac{m - 32}{\frac{t}{100} - 1} = \frac{22}{54{\cdot}33} = 0404$ $= c$, and $c \times \frac{b}{100} = 0.404 \times 8.03 = 3.24 = d$ and $m - d = 54 - 3\ 24 = 50.75$. Here we see that the temperature of the air 803 feet above the surface of the earth is 50°. 75.

From this method of estimating the diminution of temperature, which agrees remarkably well with observation, we see that the heat diminishes in an arithmetical progression. Hence it follows, that the heat of

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the air at a distance from the earth, is not owing to the ascent of hot strata of air from the surface of the earth, but to the conducting power of the air.

Upper regions warmest in winter.

3. This rule, however, applies only to the temperature of the air during the summer months of the year. In winter the upper strata of the atmosphere are often warmer than the lower. Thus on the 31st of January 1776, the thermometer on the summit of Arthur's seat stood 6 degrees higher than a thermometer at Hawkhill, which is 684 feet lower *. Mr Kirwan considers this superior heat, almost uniformly observed during winter, as owing to a current of warm air from the equator, which rolls towards the north pole during our winter †.

4. Such then, in general, is the method of finding the mean annual temperature over the globe. There are, however, several exceptions to these general rules, which come now to be mentioned.

1. North Pacific Ocean.

That part of the Pacific Ocean which lies between north lat. 52° and 66° is no broader at its northern extremity than 42 miles, and at its southern extremity than 1300 miles: it is reasonable to suppose, therefore, that its temperature will be considerably influenced by the surrounding land, which consists of ranges of mountains covered a great part of the year with snow; and there are besides a great many high, and consequently cold, islands scattered through it. For these reasons Mr Kirwan concludes, that its temperature is at least 4 or 5 degrees below the standard. But we are not yet furnished with a sufficient number of observations to determine this with accuracy.

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* Roy, *Phil. Trans.* 1777 p. 777.

† *Irish Trans.* viii. p. 375.

2. Southern hemisphere.

It is the general opinion that the southern hemisphere, beyond the 40th degree of latitude, is considerably colder than the corresponding parts of the northern hemisphere. Mr Kirwan has shewn that this holds with respect to the summer of the southern hemisphere, but that the winter in the same latitudes is milder than in the northern hemisphere *.

3. Small seas.

Small seas surrounded with land, at least in temperate and cold climates, are generally warmer in summer and colder in winter than the standard ocean, because they are a good deal influenced by the temperature of the land. The Gulph of Bothnia, for instance, is for the most part frozen in winter; but in summer it is sometimes heated to 70° ; a degree of heat never to be found in the opposite part of the Atlantic †. The German Sea is above three degrees colder in winter, and five degrees warmer in summer than the Atlantic ‡. The Mediterranean Sea is, for the greater part of its extent, warmer both in summer and winter than the Atlantic, which therefore flows into it. The Black Sea is colder than the Mediterranean, and flows into it §.

4. North America.

The eastern parts of North America are much colder than the opposite coast of Europe, and fall short of the *standard* by about 10° or 12°, as appears from American Meteorological Tables. The causes of this remarkable difference are many. The highest part of North America lies between the 40th and 50th degree of north latitude, and the 100th and 110th degree of

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* *Irish Trans.* viii. 417.

† *Mem. Stock.* 1776.

‡ Kirwan's *Temperature of Lat.* p. 53.

§ Ibid.

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longitude west from London; for there the greatest rivers originate. The very height, therefore, makes this spot colder than it otherwise would be. It is covered with immense forests, and abounds with large swamps and morasses, which render it incapable of receiving any great degree of heat; so that the rigour of winter is much less tempered by the heat of the earth than in the old continent. To the east lie a number of very large lakes; and farther north, Hudson's Bay; about 50 miles on the south of which there is a range of mountains which prevent its receiving any heat from that quarter. This bay is bounded on the east by the mountainous country of Labrador and by a number of islands. Hence the coldness of the north-west winds, and the lowness of the temperature. But as the cultivated parts of North America are now much warmer than formerly, there is reason to expect that the climate will become still milder when the country is better cleared of woods, though perhaps it will never equal the temperature of the old continent.

5. Islands.

Islands are warmer than continents in the same degree of latitude; and countries lying to the windward of extensive mountains or forests are warmer than those lying to the leeward. Stones or sand have a less capacity for heat than earth has, which is always somewhat moist; they heat or cool, therefore, more rapidly and to a greater degree. Hence the violent heat of Arabia and Africa, and the intense cold of Terra del Fuego. Living vegetables alter their temperature very slowly, but their evaporation is great; and if they be tall and close, as in forests, they exclude the sun's rays from the earth, and shelter the winter snow from the wind and the sun. Woody countries, therefore, are much colder than those which are cultivated.

SECT. III.

OF EVAPORATION AND RAIN.

Nature of vapour.

We found reason formerly to conclude, that the water of the atmosphere exists in the state of *vapour*. We are indebted to the experiments of Saussure and Deluc for much of our knowledge of the qualities of vapour. It is an elastic invisible fluid like common air, but lighter; being to common air of the same elasticity, according to Saussure, as 10 to 14, or, according to Kirwan, as 10 to 12. It cannot pass beyond a certain maximum of density, without a corresponding increase of temperature, otherwise the particles of water which compose it unite together, and form small, hollow, visible vesicles, called *vesicular vapour*; which is of the same specific gravity with atmospherical air. It is of this vapour that clouds and fogs are composed. This maximum increases with the temperature; and at the heat of boiling water is so great, that steam can resist the whole pressure of the air, and exist in the atmosphere in any quantity.

We have seen formerly, that when water is heated to 212°, it boils, and is rapidly converted into steam; and that the same change takes place in much lower temperatures; but in that case the evaporation is slower, and the elasticity of the steam is smaller. As a very considerable proportion of the earth's surface is covered with water, and as this water is constantly evaporating and mixing

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with the atmosphere in the state of vapour, a precise determination of the rate of evaporation must be of very great importance in meteorology. Accordingly many experiments have been made to determine the point by different philosophers. No person has succeeded so completely as Mr Dalton: But many curious particulars had been previously ascertained by the labours of Richman, Lambert, Wallerius, Leidenfrost, Watson, Saussure, Deluc, Kirwan, and others.

Evaporation confined to the surface.

1. The evaporation is confined entirely to the surface of the water: hence it is in all cases proportional to the surface of the water exposed to the atmosphere. Much more vapour of course rises in maritime countries, or those interspersed with lakes, than in inland countries.

Evaporation proportional to the temperature.

2. Much more vapour rises during hot weather than during cold weather. Hence the quantity evaporated depends in some measure upon temperature. The precise law has been happily discovered by Mr Dalton. This philosopher took a cylindrical vessel of tin, whose diameter was $3\frac{1}{4}$ inches, and its depth $2\frac{1}{2}$ inches; filled it with water, and kept it just boiling for some time. The loss of weight in the minute was 30 grains, when the experiment was made in a close room without any draught of air; 35 grains when the vessel was placed over fire in the usual fire-place, there being a moderate draught of air and the room close; 40 with a brisker fire and a stronger draught; and when the draught was very strong, he supposes the evaporation might amount to 60 grains in the minute. At the temperature of 180°, the quantity evaporated was $\frac{1}{2}$ of what was lost at 212°.

At 164 it was $\frac{1}{3}$ of that at 212°

152 . . . $\frac{1}{4}$

144 . . . $\frac{1}{5}$

138 . . . $\frac{1}{6}$

And in general the quantity evaporated from a given surface of water per minute at any temperature, is to the quantity evaporated from the same surface at 212°, as the force of vapour at the first temperature is to the force of vapour at 212°. Hence, in order to discover the quantity which will be lost by evaporation from water of a given temperature, we have only to ascertain the force of vapour at that temperature. This is done in the Table given in Vol. I. p. 370 of this Work. Hence we see that the presence of atmospheric air obstructs the evaporation of water; but this evaporation is overcome in proportion to the force of the vapour. Mr Dalton ascribes this obstruction to the *vis inertiæ* of air *.

3. The quantity of vapour which rises from water, even when the temperature is the same, varies according to circumstances. It is least of all in calm weather, greater when a breeze blows, and greatest of all with a strong wind. The following TABLE, drawn up by Mr Dalton, shews the quantity of vapour raised from a circular surface of 6 inches in diameter in atmospheric temperatures. The first column expresses the temperature; the second, the corresponding force of vapour; the other three columns give the number of grains of water that would be evaporated from a surface of 6 inches in diameter in the respective temperatures, on the supposition of there being previously no aqueous vapour in the atmosphere. These columns present the extremes and the mean of evaporation likely to be noticed, or nearly such; for the first is

Table of the quantity raised from a given surface at different temperatures.

* *Manchester Memoirs*, v. 577.

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calculated upon the supposition of 35 grains loss per minute from the vessel of $3\frac{1}{4}$ inches in diameter; the second 45, and the third 55 grains per minute *.

Temperature. 212°	Force of Vap. in Inch. 30°	Evaporating Force in Grains 120	154	189
20°	.129	.52	.67	.82
21	.134	.54	.69	.85
22	.139	.56	.71	.88
23	.144	.58	.73	.91
24	.150	.60	.77	.94
25	.156	.62	.79	.97
26	.162	.65	.82	1.02
27	.168	.67	.86	1.05
28	.174	.70	.90	1.10
29	.180	.72	.93	1.13
30	.186	.74	.95	1.17
31	.193	.77	.99	1 21
32	.200	.80	1.03	1.26
33	.207	.83	1.07	1.30
34	.214	.86	1.11	1.35
35	.221	.89	1.14	1.39
36	.229	.92	1.18	1.45
37	.237	.95	1.22	1.49
38	.245	.98	1.26	1.54
39	.254	1.02	1.31	1.60
40	.263	1.05	1.35	1.65
41	.273	1.09	1.40	1.71
42	.283	1.13	1.45	1.78
43	.294	1.18	1.51	1.85
44	.305	1.22	1.57	1.92
45	.316	1.26	1.62	1.99
46	.327	1.31	1.68	2.06
47	.339	1.36	1.75	2.13
48	.351	1.40	1.80	2.20
49	.363	1.45	1.86	2.28
50	.375	1.50	1.92	2.36

* *Manchester Memoirs*, v. 584.

Temperature.	Force of Vap. in Inch.	Evaporating Force in Grains.		
212°	30	120	154	189
51°	.388	1.55	1.99	2.44
52	.401	1.60	2.06	2.51
53	.415	1.66	2.13	2.61
54	.429	1.71	2.20	2.69
55	.443	1.77	2.28	2.78
56	.458	1.83	2.35	2.88
57	.474	1.90	2.43	2.98
58	.490	1.96	2.52	3.08
59	.507	2.03	2.61	3.19
60	.524	2.10	2.70	3.30
61	.542	2.17	2.79	3.41
62	.560	2.24	2.88	3.52
63	.578	2.31	2.97	3.63
64	.597	2.39	3.07	3.76
65	.616	2.46	3.16	3.87
66	.635	2.54	3.27	3.99
67	.655	2.62	3.37	4.12
68	.676	2.70	3.47	4.24
69	.698	2.79	3.59	4.38
70	.721	2.88	3.70	4.53
71	.745	2.98	3.83	4.68
72	.770	3.08	3.96	4.84
73	.796	3.18	4.09	5.00
74	.823	3.29	4.23	5.17
75	.851	3.40	4.37	5.34
76	.880	3.52	4.52	5.53
77	.910	3.65	4.68	5.72
78	.940	3.76	4.83	5.91
79	.971	3.88	4.99	6.10
80	1.00	4.00	5.14	6.29
81	1.04	4.16	5.35	6.54
82	1.07	4.28	5.50	6.73
83	1.10	4.40	5.66	6.91
84	1.14	4.56	5.86	7.17
85	1.17	4.68	6.07	7.46

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Method of finding the rate of evaporation.

4. Such is the quantity of vapour which would rise in different circumstances, on the supposition that no vapour previously existed in the atmosphere. But this is a supposition which can never be admitted, as the atmosphere is in no case totally free from vapour. We have seen already in what manner the force of the vapour existing in the atmosphere may be detected by the use of Mr Dalton's very simple apparatus. Now when we wish to ascertain the rate at which evaporation is going on, we have only to find the force of the vapour already at the atmosphere, and subtract it from the force of vapour at the given temperature. The remainder gives us the actual force of evaporation; from which, by the Table, we readily find the rate of evaporation. Thus suppose we wish to know the rate of evaporation at the temperature 59°. From the table we see that the force of vapour at 59° is 0.5, or $\frac{1}{60}$ its force at 212°. Suppose we find by trials that the force of the vapour already existing in the atmosphere is 0.25, or the half of $\frac{1}{60}$. To ascertain the rate of evaporation, we must subtract the 0.25 from 0.5; the remainder 0.25 gives us the force of evaporation required; which is precisely one half of what it would be if no vapour had previously existed in the atmosphere.

By the Table we see, that on that supposition a surface of six inches diameter would lose one grain by evaporation per minute, instead of two grains, which would have been converted into vapour if no vapour had previously existed in the atmosphere. If the force of the vapour in the atmosphere had amounted to 0.5, which is equal to the force of vapour at the temperature of 59°, in that case no vapour whatever would rise from

the water; and if the force of the vapour already in the atmosphere exceeded 0.5, instead of evaporation, moisture would be deposited on the surface of the water.

These general observations, for all of which we are indebted to Mr Dalton, account in a satisfactory manner for all the anomalies which had puzzled preceding philosophers; and include under them all the less general laws which they had discovered. We must consider the discoveries of Mr Dalton as the most important additions made to the science of meteorology for these many years.

5. As the force of the vapour actually in the atmosphere is seldom equal to the force of vapour of the temperature of the atmosphere, evaporation, with a few exceptions, may be considered as constantly going on.

Quantity evaporated from water.

Various attempts have been made to ascertain the quantity evaporated in the course of a year; but the difficulty of the problem is so great, that we can expect only an approximation towards a solution. From the experiments of Mr Dobson of Liverpool in the years 1772, 1773, 1774, and 1775, it appears that the mean annual evaporation from the surface of water amounted to 36.78 inches*. The proportion for every month was the following:

* *Phil. Trans.* vol. lxvii.—Dalton, *Manchester Memoirs*, v. 358.

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	Inches.		Inches.
January . . .	1.50	July	5.11
February . .	1.77	August . . .	5.01
March	2.64	September . .	3.18
April	3.30	October . . .	2.51
May	4.34	November . .	1.51
June	4.41	December . .	1.49

Mr Dalton found the evaporation from the surface of water in one of the driest and hottest days of summer rather more than 0.2 of an inch.

From land. If we believe Mr Williams, the evaporation from the surface of land covered with trees and other vegetables is one-third greater than from the surface of water; but this has not been confirmed by other philosophers. From his experiments * it appears, that in Bradford in New England the evaporation during 1772 amounted to 42.65 inches. But from the way that his experiments were conducted, the amount was probably too great.

From an experiment of Dr Watson made on the 2d of June 1779, after a month's drought, it appears that the evaporation, from a square inch of a grass plot, amounted to 1.2 grains in an hour, or 28.8 grains in 24 hours, which is 0.061 of an inch. In another experiment, after there had been no rain for a week, the heat of the earth being 110°, the evaporation was found almost twice as great, or =0.108 of an inch in the day †. The mean of these two experiments is 0.084 inches, amounting for the whole month of June to 2.62 inches. If we suppose this to bear the same propor-

* *Trans. Philad.* ii. 135. † Watson's *Chemical Essays*, iii. 54.

tion to the whole year that the evaporation in Dr Dobson's experiments for June do to the annual evaporation, we shall obtain an annual evaporation, amounting to about 22 inches. This is much smaller than that obtained by Mr Williams. But Dr Watson's method was not susceptible of precision. He collected the vapour raised on the inside of a drinking glass; but it was impossible that the glass could condense much more than one half of what did rise, or would have been raised in other circumstances. But to counterbalance this, the experiments were made in the hottest part of the day, when much more vapour is raised than during any part of it.

Experiments of Dalton.

The most exact set of experiments on the evaporation from earth was made by Mr Dalton and Mr Hoyle during 1796 and the two succeeding years. The method which they adopted was this. Having got a cylindrical vessel of tinned iron, 10 inches in diameter and 3 feet deep, there were inserted into it two pipes turned downwards for the water to run off into bottles: The one pipe was near the bottom of the vessel; the other was an inch from the top. The vessel was filled up for a few inches with gravel and sand, and all the rest with good fresh soil. It was then put into a hole in the ground, and the space around filled up with earth except on one side, for the convenience of putting bottles to the two pipes; then some water was poured on to sadden the earth, and as much of it as would was suffered to run through without notice, by which the earth might be considered as saturated with water. For some weeks the soil was kept above the level of the upper pipe, but latterly it was constantly a little below it, which precluded any water running off through it. For

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the first year the soil at top was bare; but for the two last years it was covered with grass the same as any green field. Things being thus circumstanced, a regular register was kept of the quantity of rain water that ran off from the surface of the earth through the upper pipe (whilst that took place), and also of the quantity of that which sunk down through the 3 feet of earth, and ran out through the lower pipe. A rain-gauge of the same diameter was kept close by to find the quantity of rain for any corresponding time. The weight of the water which ran through the pipes being subtracted from the water in the rain-gauge, the remainder was considered as the weight of the water evaporated from the earth in the vessel. The following TABLE exhibits the mean annual result of these experiments *.

	Water through the two Pipes.			Mean.	Mean Rain.	Mean Evap.
	Inch. 1796.	Inch. 1797.	Inch. 1798.	Inch.	Inch.	Inch.
Jan.	1.897—	.680—	1.774+	1.450+	2.458	1.008
Feb.	1.778—	.918—	1.122	1.273	1.801	.528
March	.431—	.070—	.335	.279	.902	.623
April	.220—	.295—	.180	.232	1.717	1.485
May	2.027—	2.443+	.010	1.493+	4.177	2.684
June	.171—	.726	——	.299	2.483	2.184
July	.153—	.025	——	.059	4.154	4.095
Aug.	——	——	.504	.168	3.554	3.386
Sept.	——	.976	——	.325	3.279	2.954
Oct.	——	.680	——	.227	2.899	2.672
Nov.	——	1.044	1.594	.879	2.934	2.055
Dec.	.200	3.077	1.878+	1.718+	3.202	1.484
	6.877—	10.934—	7.379	8.402	33.560	25.158
Rain	30.629—	38.791—	31.259			
Evap.	23.725—	27.857—	23.862			

* *Manchester Memoirs*, v. 360.

From these experiments it appears that the quantity of vapour raised annually at Manchester is about 25 inches: if to this we add 5 inches for the dew with Mr Dalton, it will make the annual evaporation 30 inches. Now if we consider the situation of England, and the greater quantity of vapour raised from water, it will not surely be considered as too great an allowance if we estimate the mean annual evaporation over the whole surface of the globe at 35 inches. Now 35 inches from every square inch on the superficies of the globe make 94,450 cubic miles, equal to the water annually evaporated over the whole globe.

Were this prodigious mass of water all to subsist in the atmosphere at once, it would increase its mass by about a twelfth, and raise the barometer nearly three inches. But this never happens; no day passes without rain in some part of the earth; so that part of the evaporated water is constantly precipitated again. Indeed it would be impossible for the whole of the evaporated water to subsist in the atmosphere at once, at least in the state of vapour.

The higher regions of the atmosphere contain less vapour than the strata near the surface of the earth. This was observed both by Saussure and Deluc, who mentions several striking proofs of it.

At some height above the tops of mountains the atmosphere is probably still drier; for it was observed both by Saussure and Deluc, that on the tops of mountains the moisture of the air was rather less during the night than the day. And there can be little doubt that every stratum of air descends a little lower during the night than it was during the day, owing to the cooling and condensing of the stratum nearest the earth. Va-

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pours, however, must ascend very high, for we see clouds forming far above the tops of the highest mountains.

Rain never begins to fall while the air is transparent: the invisible vapours first pass their maximum, and are changed into vesicular vapours; clouds are formed, and these clouds gradually dissolve in rain. Clouds, however, are not formed in all parts of the horizon at once; the formation begins in one particular spot, while the rest of the air remains clear as before: this cloud rapidly increases till it overspreads the whole horizon, and then the rain begins.

Formation of clouds

It is remarkable, that though the greatest quantity of vapours exist in the lower strata of the atmosphere, clouds never begin to form there, but always at some considerable height. It is remarkable, too, that the part of the atmosphere at which they form, has not arrived at the point of extreme moisture, nor near that point even a moment before their formation. They are not formed, then, because a greater quantity of vapour had got into the atmosphere than could remain there without passing its maximum. It is still more remarkable, that when clouds are formed, the temperature of the spot in which they are formed is not always lowered, though this may sometimes be the case. On the contrary, the heat of the clouds themselves is sometimes greater than that of the surrounding air*. Neither then is the formation of clouds owing to the capacity of air for combining with moisture being lessened by cold; so far from that, we often see clouds, which had

* Deluc *sur la Meteorol.* ii. 100

remained in the atmosphere during the heat of the day, disappear in the night, after the heat of the air was diminished.

And rain cannot be accounted for.

The formation of clouds and rain, then, cannot be accounted for by a single principle with which we are acquainted. It is neither owing to the saturation of the atmosphere, nor the diminution of heat, nor the mixture of airs of different temperatures, as Dr Hutton supposes; for clouds are often formed without any wind at all either above or below them; and even if this mixture constantly took place, the precipitation, instead of accounting for rain, would be almost imperceptible.

It is a very remarkable fact, that evaporation often goes on for a month together in hot weather without any rain. This sometimes happens in this country; it happens every year in the torrid zone. Thus at Calcutta, during January 1785, it never rained at all*: the mean of the thermometer for the whole month was 66½ degrees; there was no high wind, and indeed during great part of the month little wind at all.

The quantity of water evaporated during such a drought must be very great; yet the moisture of the air, instead of being increased, is constantly diminishing, and at last disappears almost entirely. For the dew, which is at first copious, diminishes every night; and if Dr Watson's experiment formerly mentioned be attended to, it will not be objected that the quantity of evaporation is also very much diminished. Of the very dry state to which the atmosphere is reduced du-

* *Asiatic Researches*, ii. Appendix.

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ring long droughts, the violent thunder-storms with which they often conclude is a proof, and a very decisive one. Now what becomes of all this moisture? It is not accumulated in the atmosphere above the country from which it was evaporated, otherwise the whole atmosphere would in a much less period than a month be perfectly saturated with moisture. If it be carried up daily through the different strata of the atmosphere, and wafted to other regions by superior currents of air, how is it possible to account for the different electrical state of the clouds situated between different strata, which often produces the most violent thunder-storms? Are not vapours conductors of the electric fluid; and would they not have daily restored the equilibrium of the whole atmosphere through which they passed? Had they traversed the atmosphere in this manner, there would have been no negative and positive clouds, and consequently no thunder storms. They could not have remained in the lower strata of the atmosphere, and been daily carried off by winds to other countries; for there are often no winds at all during several days to perform this office; nor in that case would the dews diminish, nor could their presence fail to be indicated by the hygrometer.

It is impossible for us to account for this remarkable fact upon any principle with which we are acquainted. The water can neither remain in the atmosphere, nor pass through it in the state of vapour. It must therefore assume some other form; but what that form is, or how it assumes it, we know not.

There are then two steps of the process between evaporation and rain, of which at present we are completely ignorant: 1. What becomes of the vapour after it

enters into the atmosphere. 2. What makes it lay aside the new form which it must have assumed, and return again to its state of vapour, and fall down in rain. And till these two steps be discovered by experiments and observations, it will be impossible for us to give a rational or a useful theory of rain.

Dr Pratt of Exeter has endeavoured to prove, in a very ingenious treatise, that water is decomposed during its evaporation, and converted into oxygen and hydrogen gas; but the absence of any perceptible quantity of this last gas in the atmosphere, even when rain is actually forming, cannot be accounted for, unless we suppose that the products of the decomposition are different. Girtanner's theory, that azote is composed of hydrogen and oxygen, would remove every difficulty; but unfortunately that theory is not only destitute of proof, but militates against the known properties of water, azote, and hydrogen. We must therefore be cautious in drawing any conclusion till future discoveries have removed the obscurity in which the phenomena of rain are at present involved.

Quantity of rain.

The mean annual quantity of rain is greatest at the equator, and decreases gradually as we approach the poles. Thus at

*Granada, Antilles,	12°	N. lat. it is	126 inches
* Cape François, St Domingo . . .	19°	46′	120
†Calcutta	22	23	81

* Cotte, *Jour. de Phys.* Oct. 1791, p. 264.

† *Asiatic Researches*, i. and ii. Appendix.

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*Rome	41°	54′	it is 39 inches
†England	33		. . . 32
‡Petersburgh . . .	59	16	. . . 16

On the contrary, the number of rainy days is smallest at the equator, and increases in proportion to the distance from it. From north latitude 12° to 43° the mean number of rainy days is 78; from 43° to 46° the mean number is 103; from 46° to 50° it is 134; from 51° to 60°, 161§.

The number of rainy days is often greater in winter than in summer; but the quantity of rain is greater in summer than in winter ‖. At Petersburgh, the number of rainy or snowy days during winter is 84, and the quantity which falls is only about five inches; during summer the number of rainy days is nearly the same, but the quantity which falls is about 11 inches ¶.

More rain falls in mountainous countries than in plains. Among the Andes it is said to rain almost perpetually, while in Egypt it hardly ever rains at all. If a rain-gauge be placed on the ground, and another at some height perpendicularly above it, more rain will be collected into the lower than into the higher; a proof that the quantity of rain increases as it descends, owing perhaps to the drops attracting vapour during their passage through the lower strata of the atmosphere where the greatest quantity resides. This, however, is not always the case, as Mr Copland of Dumfries discovered

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* Cotte, *Jour. de Phys.* Oct. 1791, p. 264.
† *Phil. Trans.* ‡ *Edin. Trans.* ii. 244.
§ Cotte, *Jour. de Phys.* Oct. 1791, p. 264.
‖ Id. Ibid. ¶ *Edin. Trans.* ii. 244.

in the course of his experiments *. He observed also, that when the quantity of rain collected in the lower gauge was greatest, the rain commonly continued for some time; and that the greatest quantity was collected in the higher gauge only either at the end of great rains, or during rains which did not last long. These observations are important, and may, if followed out, give us new knowledge of the causes of rain. They seem to show, that during rain the atmosphere is somehow or other brought into a state which induces it to part with its moisture; and that the rain continues as long as this state continues. Were a sufficient number of observations made on this subject in different places, and were the atmosphere carefully analysed during dry weather, during rain, and immediately after rain, we might soon perhaps discover the true theory of rain.

Rain falls in all seasons of the year, at all times of the day, and during the night as well as the day; tho', according to M. Toaldo, a greater quantity falls during the day than the night. The cause of rain, then, whatever it may be, must be something which operates at all times and seasons. Rain falls also during the continuance of every wind, but oftenest when the wind blows from the south. Falls of rain often happen likewise during perfect calms.

It appears from a paper published by M. Cotte in the *Journal de Physique* for October 1791, containing the mean quantity of rain falling at 147 places, situated between north lat. 11° and 60°, deduced from tables kept at these places, that the mean annual quantity of

* *Manchester Transactions*, iv. 619.

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rain falling in all these places is 34.7 inches. Let us suppose then (which cannot be very far from the truth) that the mean annual quantity of rain for the whole globe is 34 inches. The superficies of the globe consists of 170,981,012 square miles, or 686,401,498,471,475,200 square inches. The quantity of rain therefore falling annually will amount to 23,337,650,812,030,156,800 cubic inches, or somewhat more than 91,751 cubic miles of water.

The dry land amounts to 52,745,253 square miles; the quantity of rain falling on it annually therefore will amount to 30,960 cubic miles. The quantity of water running annually into the sea is 13,140 cubic miles; a quantity of water equal to which must be supplied by evaporation from the sea, otherwise the land would soon be completely drained of its moisture.

The quantity of rain falling annually in Great Britain may be seen from the following TABLE:

Years of observation.	Places.	Rain in inches.
3	Dover*	37.52
5	Ware, Hertfordshire*	23.6
8	London†	17.5
8	Kimbolton‡	23.9
45	Lyndon§	22.210
5	Chatsworth, Derbyshire* . . .	27.865
8	Manchester*	43.1
18	Liverpool*	34 41
7	Lancaster*	40.3
5	Kendal*	61.223
14	Dumfries*	36.127
10	Braxholm, 44 miles south-west of Berwick‖	31.26
5	Langholm‖	36.73
5	Dalkeith‖	25.124
20	Glasgow¶	31.
8	Hawkhill**	28.966
	Mean	32.532

Mr Dalton, in an ingenious essay on this subject, estimates the quantity of rain for England at 31 inches††; but as we have no observations kept in Wales or the Highlands of Scotland, where much rain falls, it cannot be doubted that the proportion for Britain must exceed that sum.

In this country it generally rains less in March than in November, in the proportion at a medium of 7 to 12. It generally rains less in April than October in

* *Manchester Trans.* iv.
‡ Ibid. vol. lxxix. part 1.
‖ *Edin. Trans.* i. 208.
** *Edin. Trans.* i. 333.
† *Phil. Trans.* Tables of Observations.
§ Mr Barker, Ibid.
¶ *Statist. Account of Scotland*, v. 245.
†† *Manchester Memoirs*, v. 349.

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the proportion of 1 to 2 nearly at a medium. It generally rains less in May than September, the chances that it does so are at least as 4 to 3; but when it rains plentifully in May (as 1.8 inches or more), it generally rains but little in September; and when it rains one inch or less in May, it rains plentifully in September *.

SECT. IV.

OF WIND.

No phenomenon in metcorology has more engaged the attention of men of observation than the *winds*, or those currents which so often disturb the tranquillity of the atmosphere. The subject is not only curious, but highly interesting; for upon their direction and force navigation in a great measure depends; the temperature of climates is greatly influenced by them; and they are absolutely necessary to preserve the salubrity of the atmosphere. To be acquainted with the laws by which they are regulated, and to be able to calculate beforehand the consequences of these laws, has been in every age the eager wish of philosophers. But whether it has been owing to an improper method of studying this subject, or to its lying beyond the reach of the human faculties, philosophers have not made that progress in it

* Kirwan, *Irish Trans.* v. 21.

which the sanguine imaginations of some individuals led them to expect. Many discoveries indeed have been made; and from the numbers and the genius of the philosophers at present engaged in this study, others equally important may be expected. But, notwithstanding this, many of the phenomena remain unexplained, and a rational and satisfactory theory seems still beyond our reach. I shall in this Section give as complete a detail as possible of the natural history of the winds in the different parts of the world, and then consider how they may be explained.

1. Winds in the torrid zone.

As the winds are much more regular between the tropics than in the temperate zones, it will be proper in the first place to begin with them.

Trade-wind.

In those parts of the Atlantic and Pacific Oceans which lie nearest the equator, there is a regular wind during the whole year called the *trade-wind*. On the north-side of the equator it blows from the north-east, varying frequently a point or two towards the north or east; and on the south side of it, from the south east; changing sometimes in the same manner towards the south or east. The space included between the second and fifth degree of north latitude is the internal limit of these two winds. There the winds can neither be said to blow from the north nor the south; calms are frequent, and violent storms. This space varies a little in latitude as the sun approaches either of the tropics.—In the Atlantic Ocean the trade-winds extend farther north on the American than on the African coast; and as we advance westward, they become gradually more easterly, and decrease in strength *. Their force di-

* Dr Halley, *Phil. Trans.* Abr. vol. ii. p. 134.

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minishes likewise as we approach their utmost boundaries. It has been remarked also, that as the sun approaches the tropic of Cancer, the south-east winds become gradually more southerly, and the north-east winds more easterly: exactly the contrary takes place when the sun is approaching the tropic of Capricorn *.

Monsoons.

The trade wind blows constantly in the Indian Ocean from the 10th degree of south latitude to near the 30th: But to the northward of this the winds change every six months, and blow directly opposite to their former course. These regular winds are called *monsoons*, from the Malay word *moossin*, which signifies "a season †". When they shift their direction, variable winds and violent storms succeed, which last for a month and frequently longer; and during that time it is dangerous for vessels to continue at sea.

The monsoons in the Indian Ocean may be reduced to two; one on the north and another on the south side of the equator; which extend from Africa to the longitude of New Holland and the east coast of China, and which suffer partial changes in particular places from the situation and inflection of the neighbouring countries.

1. Between the 3d and 10th degrees of south latitude the south-east trade-wind continues from April to October; but during the rest of the year the wind blows from the north-west ‡. Between Sumatra and New Holland this monsoon blows from the south during our

* Dr Halley, *Phil. Trans.* Abr vol. ii. p. 134.

† Forest's *Voyage*, p. 95.

‡ Dr Halley, *Phil. Trans.* Abr. vol. ii. p. 136.

summer months, approaching gradually to the south-east as we advance towards the coast of New Holland; it changes about the end of September, and continues in the opposite direction till April *. Between Africa and Madagascar its direction is influenced by the coast; for it blows from the north-east from October to April, and during the rest of the year from the south-west †.

2. Over all the Indian Ocean, to the northward of the 3d degree of south latitude, the north-east trade-wind blows from October to April, and a south-west wind from April to October ‡. From Borneo, along the coast of Malacca and as far as China, this monsoon in summer blows nearly from the south, and in winter from the north by east §. Near the coast of Africa, between Mozambique and Cape Guardefan, the winds are irregular during the whole year, owing to the different monsoons which surround that particular place. Monsoons are likewise regular in the Red Sea; between April and October they blow from the north-west, and during the other months from the south-east, keeping constantly parallel to the coast of Arabia ‖.

Monsoons are not altogether confined to the Indian Ocean; on the coast of Brazil, between Cape St Augustine and the island of St Catherine, the wind blows between September and April from the east or north-east, and between April and September from the south-

* Dr Halley, *Phil. Trans.* Abr vol. ii. p. 136.
† Bruce's *Travels*, vol. i. p 459.
‡ Dr Halley, *Phil. Trans.* Abr. vol. ii. p. 156.
§ Dr Halley, Ibid.
‖ Bruce's *Travels*, vol. i. ch. 4.

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west *. The bay of Panama is the only place on the west side of a great continent where the wind shifts regularly at different seasons: there it is easterly between September and March; but between March and September it blows chiefly from the south and south-west.

Such in general is the direction of the winds in the torrid zone all over the Atlantic, Pacific, and Indian Oceans; but they are subject to particular exceptions, which it is proper to enumerate. On the coast of Africa, from Cape Bayador to Cape Verde, the winds are generally north-west; from hence to the island of St Thomas near the equator they blow almost perpendicular to the shore, bending gradually, as we advance southwards, first to the west and then to the south-west †. On the coast of New Spain likewise, from California to the Bay of Panama, the winds blow almost constantly from the west or south west, except during May, June, and July, when land-winds prevail, called by the Spaniards *Popogayos*. On the coast of Chili and Peru ‡, from 20° or 30° south latitude, to the equator, and on the parallel coast of Africa, the wind blows during the whole year from the south, varying according to the direction of the land towards which it inclines, and extending much farther out to sea on the American than the African coast. The trade winds are also interrupted sometimes by westerly winds in the Bay of Campeachy and the Bay of Honduras.

As to the countries between the tropics, we are too

* Sir Walter Raleigh's *Voyage*, Forest's *Voyage*, p. 97.

† Dr Halley, *Phil. Trans.* Abr. vol. ii. p. 136.

‡ Sir Walter Raleigh's *Voyage*.—Dr Garden, *Phil. Trans*, Abr. vol ii. p. 132.

little acquainted with them to be able to give a satisfactory history of their winds.

Sea and land breezes.

In all maritime countries between the tropics of any extent, the wind blows during a certain number of hours every day *from* the sea, and during a certain number *towards* the sea from the land; these winds are called the *sea* and *land breezes*. The sea-breeze generally sets in about ten in the forenoon, and blows till six in the evening; at seven the land breeze begins, and continues till eight in the morning, when it dies away *. During summer the sea-breeze is very perceptible on all the coasts of the Mediterranean Sea †, and even sometimes as far north as Norway ‡.

Winds in St Lewis,

In the island of St Lewis on the coast of Africa, in 16° north latitude, and 16° west longitude, the wind during the rainy season, which lasts from the middle of July to the middle of October, is generally between the south and east; during the rest of the year it is for the most part east or north-east in the morning; but as the sun rises, the wind approaches gradually to the north, till about noon it gets to the west of north, and is called a *sea-breeze*. Sometimes it shifts to the east as the sun descends, and continues there during the whole night. In February, March, April, May, and June, it blows almost constantly between the north and west §. In the island of Balama, which lies likewise on the west coast of Africa, in the 11th degree of north latitude,

Balama,

* Marsden's *Hist. of Sumatra*, p. 17.—Buffon's *Nat. Hist.* vol. i. p. 385.

† Volney's *Travels*.

‡ Pontoppidan's *Natural History of Norway*.

§ Dr Schotte, *Phil. Trans.* vol. lxx. art. 25.

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the wind during nine months of the year blows from the south-west; but in November and December a very cold wind blows from the north-east *.

Bornou,

In the kingdom of Bornou, which lies between the 16th and 20th degree of north latitude, the warm season is introduced about the middle of April by sultry winds from the south-east, which bring along with them a deluge of rain †.

Fezzan,

In Fezzan, which is situated about the 25th degree of north latitude and the 35th degree of east longitude, the wind from May to August blows from the east, south-east, or south-west, and is intensely hot ‡.

Abyssinia,

In Abyssinia the winds generally blow from the west, north-west, north, and north east. During the months of June, July, August, September, and October, the north and north-east winds blow almost constantly, especially in the morning and evening; and during the rest of the year they are much more frequent than any other winds §.

East and West Indies.

At Calcutta, in the province of Bengal, the wind blows during January and February from the south-west and south; in March, April, and May, from the south; in June, July, August, and September, from the south and south-east; in October, November, and December, from the north-west ||. At Madras the most frequent winds are the north and north-east. At Tivoli in St Domingo, and at Iles de Vaches, the wind

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* P. Beaver, Esq. See Map in Wadstrom's *Essay on Colonization*.

† *African Association*, p. 200 ‡ Ibid.

§ Bruce's *Travels*, vol. iv p. 651.

|| *Asiatic Researches*, vols. i. and ii. Append.

blows oftenest from the south and south-east *. From these facts it appears, that in most tropical countries with which we are acquainted, the wind generally blows *from* the nearest ocean, except during the coldest months, when it blows *towards* it.

2. In the temperate zones,

In the temperate zones the direction of the winds is by no means so regular as between the tropics. Even in the same degree of latitude we find them often blowing in different directions at the same time; while their changes are frequently so sudden and so capricious, that to account for them has hitherto been found impossible. When winds are violent, and continue long, they generally extend over a large tract of country; and this is more certainly the case when they blow from the north or east than from any other points †. By the multiplication and comparison of Meteorological Tables, some regular connection between the changes of the atmosphere in different places may in time be observed, which will at last lead to a satisfactory theory of the winds. It is from such tables chiefly that the following facts have been collected.

In America,

In Virginia, the prevailing winds are between the south-west, west, north, and north-west; the most frequent is the south-west, which blows more constantly in June, July, and August, than at any other season. The north-west winds blow most constantly in November, December, January, and February ‡. At Ipswich in New England the prevailing winds are also be-

* P. Cotte, *Jour. de Phys.* 1791.

† Derham's *Physico-Theology*. ch. ii.

‡ Jefferson's *Virginia*, p. 123.—*Trans Philad.* ii. art. 10

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tween the south-west, west, north, and north east; the most frequent is the north-west *. But at Cambridge, in the same province, the most frequent wind is the south-east †. The predominant winds at New York are the north and west ‡: And in Nova Scotia north-west winds blow for three-fourths of the year §. The same wind blows most frequently at Montreal in Canada; but at Quebec the wind generally follows the direction of the river St Lawrence, blowing either from the north-east or south-west ||. At Hudson's Bay westerly winds blow for three fourths of the year; the north-west wind occasions the greatest cold, but the north and north-east are the vehicles of snow ¶.

It appears from these facts, that westerly winds are most frequent over the whole eastern coast of North America; that in the southern provinces south-west winds predominate; and that the north-west become gradually more frequent as we approach the frigid zone.

In Egypt,

In Egypt, during part of May, and during June, July, August, and September, the wind blows almost constantly from the north, varying sometimes in June to the west, and in July to the west and the east; during part of September, and in October and November, the winds are variable, but blow more regularly from the east than any other quarter; in December, January, and February, they blow from the north, north-west, and west; towards the end of February they

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* *Trans. Amer. Acad.* i. 336. † M. Cotte, *Jour. de Phys.* 1791.
‡ Ibid. § *Present State of Nova Scotia and Canada*, p. 38.
|| Cotte, *Jour. de Phys.* 1791.
¶ Pennant's *Suppl. to Arctic Zool.* p. 41.

change to the south, in which quarter they continue till near the end of March; during the last days of March and in April they blow from the south-east, south, and south-west, and at last from the east; and in this direction they continue during a part of May*. Chap. II.

In the Mediteranean the wind blows nearly three-fourths of the year from the north; about the equinoxes there is always an easterly wind in that sea, which is generally more constant in spring than in autumn †. These observations do not apply to the gut of Gibraltar, where there are seldom any winds except the east and the west. At Bastia, in the island of Corsica, the prevailing wind is the south-west ‡. In the Mediterranean

In Syria the north wind blows from the autumnal equinox to November; during December, January, and February, the winds blow from the west and south-west; in March they blow from the south, in May from the east, and in June from the north. From this month to the autumnal equinox the wind changes gradually as the sun approaches the equator; first to the east, then to the south, and lastly to the west §. At Bagdad the most frequent winds are the south-west and north-west; at Pekin, the north and the south ‖; at Kamtschatka, on the north east coast of Asia, the prevailing winds blow from the west ¶. Asia,

In Italy the prevailing winds differ considerably according to the situation of the places where the observations have been made: At Rome and Padua they are South of Europe,

* Volney's *Travels*, i. 58.
† Ibid. i. 59. and 65.
‡ Cotte, *Jour. de Phys.* 1791.
§ Volney's *Travels*, i. 326.
‖ Cotte, Ibid.
¶ Pennant's *Arctic Zool.* p. cxiii.

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northerly, at Milan easterly *. All that we have been able to learn concerning Spain and Portugal is, that on the west coast of these countries the west is by far the most common wind, particularly in summer; and that at Madrid the wind is north-east for the greatest part of the summer, blowing almost constantly from the Pyrenean mountains †. At Berne in Switzerland the prevailing winds are the north and west; at St Gottard, the north-east; at Lausanne, the north-west and south-west ‡.

France,

Father Cotte has given us the result of observations made at 86 different places of France ‡; from which it appears, that along the whole south coast of that kingdom the wind blows most frequently from the north, north-west, and north-east; on the west coast, from the west, south-west, and north-west; and on the north coast, from the south-west. That in the interior parts of France the south-west wind blows most frequently in 18 places; the west wind in 14; the north in 13; the south in 6; the north-east in 4; the south-east in 2; the east and north-west each of them in one.—On the west coast of the Netherlands, as far north as Rotterdam, the prevailing winds are probably the south-west, at least this is the case at Dunkirk and Rotterdam ‡. It is probable also that along the rest of this coast, from the Hague to Hamburgh, the prevailing winds are the north-west, at least these winds are most frequent at the Hague and at Franeker ‡.—The prevailing wind at Delft is the south-east; and at Breda the north and the east ‡.

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* Cotte, *Jour. de Phys.* 1791.

† Bohun's *Hist. of Winds*, p. 116.

‡ Cotte, *Jour. de Phys*, 1791.

In Germany the east wind is most frequent at Gottingen, Munich, Weissemburgh, Dusseldorf, Saganum, Erford, and at Buda in Hungary; the south-east at Prague and Wirtzburg; the north-east at Ratisbon; and the west at Manheim and Berlin *. Germany.

From an average of ten years of the register kept by order of the Royal Society, it appears that at London the winds blow in the following order: Britain.

Winds.	Days.	Winds.	Days.
South-west	112	South-east	32
North-east	58	East	26
North-west	50	South	18
West	53	North	16

It appears, from the same register, that the south-west wind blows at an average more frequently than any other wind during every month of the year, and that it blows longest in July and August; that the north-east blows most constantly during January, March, April, May, and June, and most seldom during February, July, September, and December: and that the north-west wind blows oftener from November to March, and more seldom during September and October than any other months. The south-west winds are also most frequent at Bristol, and next to them are the north-east †.

The following TABLE of the winds at Lancaster has been drawn up from a register kept for seven years at that place‡.

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* Cotte, *Jour. de Phys.* 1791. † *Phil. Trans.* lxvi. 2.

‡ *Manchester Transactions*, iv. 234.

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Winds.	Days.	Winds.	Days.
South-west	92	South-east	35
North-east.	67	North	30
South	51	North-west	26
West	41	East	17

The following TABLE is an abstract of nine years observations made at Dumfries by Mr Copland †.

Winds.	Days.	Winds.	Days.
South	82½	North	36½
West	69	North-west . . .	25½
East	68	South-east . . .	18½
South-west	50½	North-east	14½

The following TABLE is an abstract of seven years observations made by Dr Meek at Cambuslang near Glasgow ‡.

Winds.	Days.	Winds.	Days.
South-west	174	North-east	104
North-west	40	South-east	47

It appears, from the register from which this Table was extracted, that the north-east wind blows much more frequently in April, May, and June, and the south-west in July, August, and September, than at any other period. The south-west is by far the most frequent wind all over Scotland, especially on the west coast. At Saltcoats in Airshire, for instance, it blows three-fourths of the year; and along the whole coast of Murray, on the north-east side of Scotland, it blows for two-thirds of the year. East winds are common over all Great Britain during April and May; but

* *Manchester Transactions*, iv. 234.

† *Statistical Account of Scotland*, v. 245.

their influence is felt most severely on the eastern coast.

The following TABLE exhibits a view of the number of days during which the westerly and easterly winds blow in a year at different parts of the island. Under the term *westerly* are included the north-west, west, south-west, and south; the term *easterly* is taken in the same latitude.

Years of Observ.	Places.	Wind. Westerly.	Easterly.
10	London	233	132
7	Lancaster	216	149
51	Liverpool*	190	175
9	Dumfries	227·5	137·5
10	Branxholm, 54 miles south-west of Berwick†	232	133
7	Cambuslang	214	151
8	Hawkhill, near Edinburgh‡	229·5	135·5
	Mean	220.3	144·7

In Ireland the south-west and west are the grand trade-winds, blowing most in summer, autumn, and winter, and least in spring. The noth-east blows most in spring, and nearly double to what it does in autumn and winter. The south-east and north-west are nearly equal, and are most frequent after the south-west and west §. Ireland,

At Copenhagen the prevailing winds are the east North of Europe.

* *Manchester Trans.* iv. † *Edin. Trans.* i. 203. ‡ Ibid.

§ *Rutty's Hist. of the Weather, &c. in Dublin.*

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and south-east; at Stockholm, the west and north *. In Russia, from an average of a register of 16 years, the winds blow from November to April in the following order:

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	45	26	23	22	20	19	14	12

And during the other six months,

	W.	N.W.	E.	S.W.	S.	N.E.	N.	S.E.
Days	27	27	19	24	22	15	32	18

The west wind blows during the whole year 72 days; the north-west 53; the south-west and north 46 days each. During summer it is calm for 41 days, and during winter for 21 †. In Norway the most frequent winds are the south, the south-west, and south-east. The wind at Bergen is seldom directly west, but generally south-west or south-east; a north-west, and especially a north-east wind, are but little known there ‡.

From the whole of these facts, it appears that the most frequent winds on the south coasts of Europe are the north, the north-east, and north-west; and on the western coast, the south-west: that in the interior parts which lie most contiguous to the Atlantic ocean, south-west winds are also most frequent; but that easterly winds prevail in Germany. Westerly winds are also most frequent on the north-east coast of Asia.

3. South temperate zone.

It is probable that the winds are more constant in the south temperate zone, which is in a great measure covered with water, than in the north temperate zone, where their direction must be frequently interrupted and altered by mountains and other causes.

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* Cotte, *Jour. de Phys.* 1791.

† Guthrie on the Climate of Russia, *Edin. Trans.* ii.

‡ Pontoppidan's *Nat. Hist. of Norway*, part i.

M. de la Caille, who was sent thither by the French king to make astronomical observations, informs us, that at the Cape of Good Hope the main winds are the south-east and north-west; that other winds seldom last longer than a few hours; and that the east and north-east winds blow very seldom. The south-east wind blows in most months of the year, but chiefly from October to April; the north-west prevails during the other six months, bringing along with it rain, and tempests, and hurricanes. Between the Cape of Good Hope and New Holland the winds are commonly westerly, and blow in the following order: north-west, south-west, west, north *.

In the Great South Sea, from latitude 30° to 40° south, the south-east trade-wind blows most frequently, especially when the sun approaches the tropic of Capricorn; the wind next to it in frequency is the north-west, and next to that is the south-west. From south latitude 40° to 50° the prevailing wind is the north-west, and next the south-west. From 50° to 60°, the most frequent wind is also the north-west, and next to it is the west †.

Thus it appears that the trade-winds sometimes extend farther into the south temperate zone than their usual limits, particularly during summer; that beyond their influence the winds are commonly westerly, and that they blow in the following order: north-west, south-west, west.

Such is the present state of the history of the direc-

* Meteorological Tables at the end of Philip's and White's *Voyages*.

† Wales's *Meteor. Tables*.

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tion of the winds. In the torrid zone they blow constantly from the north-east on the north side of the equator, and from the south-east on the south side of it. In the north temperate zone they blow most frequently from the south-west; in the south temperate zone from the north-west, changing, however, frequently to all points of the compass; and in the north temperate zone blowing, particularly during spring, from the north-east.

Velocity of the winds.

As to the velocity of the wind, its variations are almost infinite; from the gentlest breeze to the hurricane which tears up trees and blows down houses. It has been remarked, that our most violent winds take place when neither the heat nor the cold is greatest; that violent winds generally extend over a great tract of country; and that they are accompanied by sudden and great falls in the mercury of the barometer. The wind is sometimes very violent at a distance from the earth, while it is quite calm at its surface. On one occasion Lunardi went at the rate of 70 miles an hour in his balloon, though it was quite calm at Edinburgh when he ascended, and continued so during his whole voyage. The following TABLE, drawn up by Mr Smeaton, will give the reader a pretty precise idea of the velocity of the wind in different circumstances *.

* *Phil. Trans.* 1759, p. 165.

Miles Per Hour.	Feet per Second.	Perpendicular Force on one square Foot, in Avoirdupois Pounds and Parts.	
1	1.47	.005	Hardly perceptible
2	2.93	.020	Just perceptible
3	4.4	.044	
4	5.87	.079	Gently pleasant
5	7.33	.123	
10	14.67	.492	Pleasant, brisk
15	22.	1.107	
20	29.34	1.968	Very brisk
25	36.67	3.075	
30	44.01	4.429	High wind
35	51.34	6.027	
40	58.68	7.873	Very high wind
45	66.01	9.963	
50	73.35	12.300	Storm or tempest
60	88.02	17.715	Great storm
80	117.36	31.490	Hurricane
100	146.7	49.200	Hurricane that tears up trees and carries buildings before it.

Let us now consider the cause of these numerous currents in the atmosphere.

Explanation of the cause of the trade-winds.

It cannot be doubted that the surface of the earth under the torrid zone is much more heated by the rays of the sun than under the frozen or temperate zones, because the rays fall upon it much more perpendicularly. This heat is communicated to the air near the surface of the torrid zone, which being thereby rarefied, ascends; and its place is supplied by colder air, which rushes in from the north and south.

Now the diurnal motion of the earth is greatest at the equator, and diminishes gradually as we approach the poles, where it ceases altogether. Every spot of the earth's surface at the equator moves at the rate of

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15 geographical miles in a minute; at the 40° of latitude, it moves at about 11½ miles in a minute; and at the 30°, at nearly 13 miles. The atmosphere, by moving continually round along with the earth, has acquired the same degree of motion; so that those parts of it which are above the equator move faster than those which are at a distance. Were a portion of the atmosphere to be transported in an instant from latitude 30° to the equator, it would not immediately acquire the velocity of the equator; the eminences of the earth therefore would strike against it, and it would assume the appearance of an east wind. This is the case in a smaller degree with the air that flows towards the equator, to supply the place of the rarefied air, which is continually ascending; and this, when combined with its real motion from the north and south, must cause it to assume the appearance of a north-easterly wind on this side the equator, and of a south-easterly beyond it †.

The motion westwards occasioned by this difference in celerity alone would scarcely be perceptible; but it is much increased by another circumstance. Since the rarefaction of the air in the torrid zone is owing to the heat derived from the contiguous earth, and since this heat is owing to the perpendicular rays of the sun, those parts must be hottest where the sun is actually vertical, and consequently the air over them must be most rarefied; the contiguous parts of the atmosphere will therefore be drawn most forcibly to that particular spot. Now since the diurnal motion of the sun is from east

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† This cause of the trade-winds was first assigned by Hadley in 1734. See *Phil. Trans. Abridg.* viii. 500.

to west, this hottest spot will be continually shifting westwards, and this will occasion a current of the atmosphere in that direction. That this cause really operates, appears from a circumstance already mentioned: when the sun approaches either of the tropics, the trade-wind on the same side of the equator assumes a more easterly direction, evidently from the cause here mentioned; while the opposite trade-wind, being deprived of this additional impulse, blows in a direction more perpendicular to the equator*.

The westerly direction of the trade-winds is still farther increased by another cause. Since the attraction of the sun and moon produces so remarkable an effect upon the ocean, we cannot but suppose that an effect equally great at least is produced upon the atmosphere. Indeed as the atmosphere is nearer the moon than the sea is, the effect produced by attraction upon it ought to be greater. When we add to this the elasticity of the air, or that disposition which it has to dilate itself when freed from any of its pressure, we cannot but conclude that the tides in the atmosphere are considerable. Now since the apparent diurnal motion of the moon is from east to west, the tides must follow it in the same manner, and consequently produce a constant motion in the atmosphere from east to west†.

All these different causes probably combine in the production of the trade-winds; and from their being

* This cause was first assigned by Dr Halley in his essay on the trade-winds; and is certainly by far the most powerful of all the agents.

† This cause was first assigned by D'Alembert in his dissertation *on the Cause of the Winds.*

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sometimes united, and sometimes distinct or opposite, arise all those little irregularities which take place in the direction and force of the trade-winds.

Why their limit is in the northern hemisphere.

Since the great cause of these winds is the rarefaction of the atmosphere by the heat of the sun, its ascension, and the consequent rushing in of colder air from the north and south, the internal boundary of the trade-winds must be that parallel of the torrid zone which is hottest, because there the ascension of the rarefied air must take place. Now since the sun does not remain stationary, but is constantly shifting from one tropic to the other, we ought naturally to expect that this boundary would vary together with its exciting cause; that therefore when the sun is perpendicular to the tropic of Cancer, the north-east trade-winds would extend no farther south than north latitude 23.5°; that the south-east wind would extend as far north; and that when the sun was in the tropic of Capricorn, the very contrary would take place. We have seen, however, that though this boundary be subject to considerable changes from this very cause, it may in general be considered as fixed between the second and fifth degrees of north latitude.

Though the sun be perpendicular to each of the tropics during part of the year, he is for one half of it at a considerable distance; so that the heat which they acquire while he is present is more than lost during his absence. But the sun is perpendicular to the equator twice in a year, and never farther distant from it than $23\frac{1}{2}°$: being therefore twice every year as much heated, and never so much cooled as the tropics, its mean heat must be greater, and the atmosphere in consequence generally most rarefied at that place. Why then, it will

be asked, is not the equator the boundary of the two trade-winds? To speak more accurately than we have hitherto done, the internal limit of these winds must be that parallel where the mean heat of the earth is greatest. This would be the equator, were it not for a reason which shall now be explained.

It has been shewn by astronomers, that the orbit of the earth is an ellipsis, and that the sun is placed in one of the foci. Were this orbit to be divided into two parts by a straight line perpendicular to the transverse axis, and passing through the centre of the sun, one of these parts would be less than the other; and the earth, during its passage through this smaller part of its orbit, would constantly be nearer the sun than while it moved through the other portion. The celerity of the earth's motion in any part of its orbit is always proportioned to its distance from the sun; the nearer it is to the sun, it moves the faster; the farther distant, the slower. The earth passes over the smaller portion of its orbit during our winter; which must therefore be shorter than our summer, both on account of this part of the orbit being smaller than the other, and on account of the increased celerity of the earth's motion. The difference, according to Cassini, is 7 days, 23 hours, and 53 minutes. While it is winter in the northern it is summer in the southern hemisphere; wherefore the summer in the southern hemisphere must be just as much shorter than the winter as our winter is shorter than our summer. The difference therefore between the length of the summer in the two hemispheres is almost 16 days. The summer in the northern hemisphere consists of 190½ days, while in the southern it consists only of 174½. They are to one another nearly in the propor-

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tion of 14 to 12.8; and the heat of the two hemispheres may probably have nearly the same proportion to one another. The internal limit of the trade-winds ought to be that parallel where the mean heat of the globe is greatest: this would be the equator, if both hemispheres were equally hot; but since the northern hemisphere is the hottest, that parallel ought to be situated somewhere in it; and since the difference between the heat of the two hemispheres is not great, the parallel ought not to be far distant from the equator*.

* This parallel could be determined by calculation, provided the mean heat of both the segments into which it divides the globe were known. Let the radius of this globe be $= 1$, the circumference of a great circle $= 6$, and consequently the arc of a great circle $= 3$, and the solid contents of a hemisphere $= 2$. Since the internal limit of the trade-winds is not far distant from the equator, we may consider that portion of the sphere intercepted between it and the equator as a cylinder, the base of which is the equator, and its height the arc intercepted between the equator and the internal limit of the trade-winds. Let this arc be x, and consequently the cylinder itself $= 3x$, equal to the excess of the southern segment into which this internal limit divides the globe above the northern. Let the heat of the northern segment be $= n$, and that of the northern $= s$, The southern segment is $= 2 + 3x$, the northern $= 2 - 3x$. Now let us suppose that the bulk of each segment is reciprocally as its heat, and we shall have this formula, $2 + 3x : 2 - 3x :: n : s$. Wherefore $x = \frac{2n - 2s}{3n + 3s}$. Now if we suppose $n = 14$, and $s = 12.8$, $\frac{2n - 2s}{3n + 3s}$ is $= \frac{24}{804}$. To reduce this value of x to degrees we must multiply it by 60, since a great circle was made $= 6$: it gives $1^{\circ}\ 48'\ 27''$ as the nternal limit of the trade-wind. This is too small by $2^{\circ}\ 11'\ 33''$. But the value which we have found is only that of the sine of the arc intercepted between the equator and the internal limit; the are itself would be somewhat greater; besides, the proportion between the heat of the two segments is an assumed quantity, and may probably be greater than their difference in bulk: and one reason for this may be the great proportion of land in the northern compared with the southern segments. See the *Journal de Physique*, *Mai* 1791.

Causes of the moonsoons.

The trade-wind would blow regularly round the whole globe if the torrid zone were all covered with water. If the Indian Ocean were not bounded by land on the north, it would blow there in the same manner as it does in the Atlantic and Pacific Oceans. The rays of light pass through a transparent body without communicating any, or at least but a small degree of heat. If a piece of wood be inclosed in a glass vessel, and the focus of a burning glass directed upon it, the wood will be burnt to ashes, while the glass through which all the rays passed is not even heated. When an opaque body is exposed to the sun's rays, it is heated in proportion to its opacity. If the bulb of a thermometer be exposed to the sun, the quicksilver will not rise so high as it would do if this bulb were painted black. Land is much more opaque than water; it becomes therefore much warmer when both are equally exposed to the influence of the sun. For this reason, when the sun approaches the tropic of Cancer, India, China, and the adjacent countries, become much hotter than the ocean which washes their southern coasts. The air over them becomes rarefied and ascends, while colder air rushes in from the Indian Ocean to supply its place. As this current of air moves from the equator northward, it must, for a reason already explained, assume the appearance of a south-west wind; and this tendency eastward is increased by the situation of the countries to which it flows. This is the cause of the south-west monsoon, which blows during summer in the northern parts of the Indian Ocean. Between Borneo and the coast of China its direction is almost due north, because the country to which the current is directed lies rather

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to the west of north; a circumstance which counteracts its greater velocity.

In winter, when the sun is on the south side of the equator, these countries become cool, and the north-east trade-wind resumes its course, which, had it not been for the interference of these countries, would have continued the whole year.

As the sun approaches the tropic of Capricorn, it becomes almost perpendicular to New Holland: that continent is heated in its turn, the air over it is rarefied, and colder air rushes in from the north and west to supply its place. This is the cause of the north-west monsoon, which blows from October to April from the 3d to the 10th degree of south latitude. Near Sumatra its direction is regulated by the coast: this is the case also between Africa and Madagascar.

The same cause which occasions the monsoons gives rise to the winds which blow on the west coasts of Africa and America. The air above the land is hotter and rarer, and consequently lighter than the air above the sea; the sea air therefore flows in, and forces the lighter land atmosphere to ascend.

And of the sea and land breezes.

The same thing will account for the phenomena of the sea and land breezes. During the day, the cool air of the sea, loaded with vapours, flows in upon the land, and takes the place of the rarefied land air. As the sun declines, the rarefaction of the land air is diminished: thus an equilibrium is restored. As the sea is not so much heated during the day as the land, neither is it so much cooled during the night; because it is constantly exposing a new surface to the atmosphere. As the night approaches, therefore, the cooler and denser air of the hills (for where there are no hills there are no

sea and land breezes) falls down upon the plains, and, pressing upon the now comparatively lighter air of the sea, causes the land-breeze.

The rarefied air which ascends between the second and fifth degrees of north latitude has been shewn to be the principal cause of the trade-winds. As this air ascends, it must become gradually colder, and consequently heavier; it would therefore descend again if it were not buoyed up by the constant ascent of new rarefied air. It must therefore spread itself to the north and south, and gradually mix in its passage with the lower air; and the greater part of it probably does not reach far beyond the 30°, which is the external limit of the trade-wind. Thus there is a constant circulation of the atmosphere in the torrid zone; it ascends near the equator, diffuses itself towards the north and south, descends gradually as it approaches the 30°, and returning again towards the equator performs the same circuit.

Cause of south-west winds.

If the attraction of the moon and the diurnal motion of the sun have any effect upon the atmosphere, and that they have some effect can hardly be disputed, there must be a real motion of the air westwards within the limits of the trade-winds. The consequence of this westerly current is an easterly current on its north and south side, as has been demonstrated by D'Alembert. Hence the frequency of south-west winds over the Atlantic Ocean and the western parts of Europe.

Mr Kirwan has rendered it probable that the frequency of south-west winds, in our latitudes at least during winter, is owing to an opposite current, which blows in the eastern parts of our hemisphere, between the coast of Malabar and the Moluccas during the same season. This northern wind must be supplied from countries

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still farther north to the pole, which must be recruited in its turn from the countries to the south of it in the western parts of our hemisphere *.

Our theory of the variable winds is still too imperfect to attempt any thing like a satisfactory explanation of them. They evidently stamp the nature of every climate, and therefore depend upon causes which act with uniformity, notwithstanding all their apparent irregularity. They are all intimately connected with each other, and probably succeed each other in a certain order, though that order has not hitherto been observed. All that can be done at present is to offer a few unconnected remarks.

Winds appear usually to begin at that point towards which they blow †. They must therefore be owing to a rarefaction or displacing of the air in some particular quarter, either by the action of heat or some other cause. This is more particularly the case when the wind blows with violence. Hurricanes are uniformly preceded by a great fall of the barometer; and the wind often flows in every direction towards the place where the barometer stands so low. One would be tempted in this case to suppose the sudden decomposition of a portion of the atmosphere. Strong north-east winds have been repeatedly observed beginning at the quarter towards which they flow. In 1740 Dr Franklin was prevented from observing an eclipse of the moon at Philadelphia by a north-east storm, which came on about seven o'clock in the evening. He was surprised to find afterwards that it had not come on at Boston till near 11 o'clock:

* *Irish Trans.* viii. 400.

† Kirwan, Ibid. p. 397.

and upon comparing all the accounts which he received from the several colonies of the beginning of this and other storms of the same kind, he found it to be always an hour later the farther north-east for every 100 miles.

"From hence (says he) I formed an idea of the course of the storm, which I will explain by a familiar instance. I suppose a long canal of water stopped at the end by a gate. The water is at rest till the gate is opened; then it begins to move out through the gate, and the water next the gate is first in motion, and moves on towards the gate; and so on successively, till the water at the head of the canal is in motion, which it is last of all. In this case all the water moves indeed towards the gate; but the successive times of beginning the motion are in the contrary way, viz. from the gate back to the head of the canal. Thus, to produce a north-east storm, I suppose some great rarefaction of the air in or near the Gulf of Mexico; the air rising thence has its place supplied by the next more northern, cooler, and therefore denser and heavier air; a successive current is formed, to which our coast and inland mountains give a north-east direction *."

A similar storm was observed by Dr Mitchell in 1802. It began at Charlestown on the 21st February, at two o'clock in the afternoon; at Washington, which lies several hundred miles to the north-east, it was not observed till five o'clock; at New York it began at ten in the evening; and at Albany not till day-break

* Franklin's *Philosophical Letters*, p. 389.

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of the 22d. Its motion, from this statement, was 1100 miles in 11 hours, or 100 miles in the hour *.

A remarkable storm of the same kind, and accompanied by an easterly wind, was observed in Scotland on the 8th of February 1799. It was attended by a very heavy fall of snow, and the motion of the wind was much slower. At Falkirk it began to snow at six in the evening of the 7th; at Edinburgh about one o'clock in the morning of the 8th; and at Dunbar at eight o'clock in the morning. It lasted 11 hours, and did not travel above 100 miles during that time.

The north-east wind blows most frequently with us during the spring months; and from the observations made by Captain Cook, it appears that the same wind prevails during the same period in the Northern Pacific. Hence it appears that at that season the cold air from the north of Europe and America flows into the Atlantic and Pacific. Hence the reason of its uncommon coldness, dryness, and density.

It is very common to observe one current of air blowing at the surface of the earth, while a current flows in a contrary direction in the higher strata of the atmosphere. On one occasion I even observed three such winds blowing in contrary directions all at the same time. It is affirmed that changes of weather generally begin in the upper strata of the air; the wind which blows there gradually extending itself to the surface of the earth †.

Partial winds.

Besides these more general winds, there are others

* *Phil. Mag.* xiii. 272

† Derham and Gentil.—Kirwan, *Irish Trans.* viii. 404.

which extend only over a very small part of the earth. These originate from many different causes. The atmosphere is composed of three different substances, air, vapour, and carbonic acid; to which may be added water. Great quantities of each of these ingredients are constantly changing their aerial form, and combining with various substances; or they are separating from other bodies, assuming the form of air, and mixing with the atmosphere. Partial voids, therefore, and partial accumulations, must be continually taking place in different parts of the atmosphere, which will occasion winds varying in direction, violence, and continuance, according to the suddenness and the quantity of air destroyed or produced. Besides these there are many other ingredients constantly mixing with the atmosphere, and many partial causes of condensation and rarefaction in particular places. To these, and other causes probably hitherto unknown, are to be ascribed all those winds which blow in any place besides the general ones already explained; and which, as they depend on causes hitherto at least reckoned contingent, will probably for ever prevent uniformity and regularity in the winds. All these causes, however, may, and probably will, be discovered; the circumstances in which they will take place, and the effects which they will produce, may be known; and whenever this is the case, the winds of any place may in some measure be reduced to calculation.

SECT. V.

OF ATMOSPHERICAL ELECTRICITY.

AIR is one of those bodies which have received the name of *electric*, because they are capable of being positively or negatively charged with electric matter. It not only contains that portion of electricity which seems necessary to the constitution of all terrestrial bodies, but it is liable also to be charged negatively or positively when electricity is abstracted or introduced by means of conducting bodies. These different states must occasion a variety of phenomena, and in all probability contribute very considerably to the various combinations and decompositions which are continually going on in air. The electrical state of the atmosphere, then, is a point of considerable importance, and has with great propriety occupied the attention of philosophers ever since Dr Franklin demonstrated that thunder is occasioned by the agency of electricity.

Electricity of the atmosphere.

1. The most complete set of observations on the electricity of the atmosphere were made by Professor Beccaria of Turin. He found the air almost always positively electrical, especially in the day-time and in dry weather. When dark or wet weather clears up, the electricity is always negative. Low thick fogs rising into dry air carry up a great deal of electric matter.

2. In the morning, when the hygrometer indicates dryness equal to that of the preceding day, positive

electricity obtains even before sunrise. As the sun gets up, this electricity increases more remarkably if the dryness increases. It diminishes in the evening.

3. The mid-day electricity of days equally dry is proportional to the heat.

4. Winds always lessen the electricity of a clear day, especially if damp.

5. For the most part, when there is a clear sky and little wind, a considerable electricity arises after sunset at dew falling.

6. Considerable light has been thrown upon the sources of atmospherical electricity by the experiments of Saussure and other philosophers. Air is not only electrified by friction like other electric bodies, but the state of its electricity is changed by various chemical operations which often go on in the atmosphere. Evaporation seems in all cases to convey electric matter into the atmosphere; and Saussure has ascertained that the quantity of electricity is much increased when water is decomposed, as when water is dropt on a red hot iron. On the other hand, when steam is condensed into vesicular vapour, or into water, the air becomes negatively electric. Hence it would seem that electricity enters as a component part into water; that it separates when water is decomposed or expanded into steam, and is reunited when the steam is condensed again into water.

Farther, Mr Canton has ascertained that dry air, when heated, becomes negatively electric, and positive when cooled, even when it is not permitted to expand or contract: and the expansion and contraction of air also occasions changes in its electric state.

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Sources of it.

Thus there are four sources of atmospheric electricity known: 1. Friction; 2. Evaporation; 3. Heat and cold; 4. Expansion and contraction: not to mention the electricity evolved by the melting, freezing, solution, &c. of various bodies in contact of air.

Consequences of its accumulation.

7. As air is an electric, the matter of electricity, when accumulated in any particular strata, will not immediately make its way to the neighbouring strata, but will induce in them changes similar to what is induced upon plates of glass or similar bodies piled upon each other. Therefore if a stratum of air be electrified positively, the stratum immediately above it will be negative, the stratum above that positive, and so on. Suppose now that an imperfect conductor were to come into contact with each of these strata, we know from the principles of electricity that the equilibrium would be restored, and that this would be attended with a loud noise, and with a flash of light. Clouds which consist of vesicular vapours mixed with particles of air are imperfect conductors; if a cloud therefore come into contact with two such strata, a thunder clap would follow. If a positive stratum be situated near the earth, the intervention of a cloud will, by serving as a stepping-stone, bring the stratum within the striking distance, and a thunder-clap will be heard while the electrical fluid is discharging itself into the earth. If the stratum be negative, the contrary effects will take place. It does not appear, however, that thunder is often occasioned by a discharge of electric matter from the earth into the atmosphere. The accidents, most of them at least, which were formerly ascribed to this cause, are now much more satisfactorily accounted for

by Lord Stanhope's *Theory of the Returning Stroke*. Neither does it appear that electricity is often discharged into the earth, as the effects of few thunder-storms are visible upon the earth; that it is so sometimes, however, is certain.

Occasions a kind of combustion in air.

But it is not the province of chemistry to examine in detail the phenomena of thunder; that task must be resigned to the electrical philosopher. There is one remark, however, which cannot be omitted; it is this, that, during every discharge of electricity, whether natural or artificial, through air, some change similar to combustion undoubtedly takes place. The light and the peculiar smell with which all electrical discharges are accompanied demonstrate this; for no light is perceptible when electricity is discharged in a vacuum. What the change is which electricity produces in air, or how it produces it, are questions which, in the present state of our knowledge, are altogether insoluble. But the very extraordinary Galvanic phenomena which at present occupy the attention of philosophers, promise not only to throw light upon this important subject, but to demonstrate a much closer connection between chemistry and electricity than has hitherto been suspected.

SECT. VI.

OF THE STONES WHICH FALL FROM THE ATMOSPHERE.

NOTHING can be a more complete proof of the imperfect state of the science of Meteorology, than the discovery of facts, for which not even a conjectural cause in the smallest degree probable can be assigned. Luminous bodies called *meteors*, *fire balls*, &c. have in all ages been observed in the atmosphere, and many of them have been described by eye-witnesses. One of the most remarkable of these, was the meteor which appeared in 1783. It was very luminous, and its diameter could not be less than 1000 yards. It traversed Britain and a considerable part of the continent of Europe with very great velocity, and at the height of nearly 60 miles from the surface of the earth *. Almost all the meteors observed resembled each other. They were luminous, at a great height, moved very swiftly, and disappeared in a very short time. Their disappearance was usually accompanied by a loud explosion like a clap of thunder; and it was almost constantly affirmed, that heavy stony bodies fell from them to the earth. But though several well authenticated accounts of the fall of such stones had been from time to time published, lit-

History.

* See Cavallo's description of it, *Phil. Trans.* 1784.

tle credit was given to them; nor did they indeed attract the attention of philosophers, till Dr Chladni published a dissertation on the subject in 1794. Two years after Mr King published a still more complete collection of examples, both ancient and modern; many of them supported by such evidence that it was impossible to reject it. These two dissertations excited considerable attention: but the opinion that stones had really fallen from the atmosphere, was considered as so extraordinary, and so contrary to what we know of the constitution of the air, that most people hesitated or refused their assent. Meanwhile Mr Howard took a different method of investigating the subject. He not only collected all the recent and well authenticated accounts of the fall of stony bodies, and examined the evidence of their truth, but procured specimens of the stones which were said to have fallen in different places, compared them together, and subjected them to a chemical analysis. The result was, that all these stony bodies differ completely from every other known stone; that they all resemble each other, and that they are all composed of the same ingredients. His dissertation on the subject was published in the Philosophical Transactions for 1802. The proofs which this admirable dissertation contains, that the stony bodies in question really fell from the atmosphere, are quite irresistible. Indeed their external characters and chemical analysis would alone decide the point: For it is quite inconceivable that in India, England, France, Germany, and Italy, in climates and in soils exceedingly different from each other, stones should have been pointed out which differed from every other mineral in the countries where they were found, and which exactly resembled one another, provided

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these had not had the same origin. The chemical analysis of Howard was soon after repeated, and verified by Vauquelin * and Klaproth †.

Table of the best authenticated instances of the fall of stones.

1. Most of the stones which have fallen from the atmosphere have been preceded by the appearance of luminous bodies or meteors. These meteors burst with an explosion, and then the shower of stones falls to the earth. Sometimes the stones continue luminous till they sink into the earth; but most commonly their luminousness disappears at the time of the explosion. These meteors move in a direction nearly horizontal, and they seem to approach the earth before they explode. The following TABLE, drawn up by Mr Izarn, exhibits the collection of the best authenticated instances of the falling of stones from the atmosphere hitherto observed, together with the time when they fell, and the persons on whose evidence the fact rests ‡.

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* *Ann. de Chim.* xlv. 225. † *Phil. Mag.* xv. 182.
‡ bid. xvi. 298.

Substances.	Places where they fell.	Period of their Fall.	Testimony.
Shower of stones	At Rome	Under Tullus Hostilius	Livy
Shower of stones	At Rome	Consuls C. Martius & M. Torquatus	J. Obsequens
Shower of iron	In Lucania	Year before the defeat of Crassus	Pliny
Shower of mercury	In Italy		Dion
A very large stone	Near the river Negos, Thrace	Second year of the 78th Olympiad	Pliny
Three large stones	In Thrace	Year before J. C. 452	Ch. of Count Marcellin.
Shower of fire	At Quesnoy	January 4th 1717	Geoffroy le Cadet
Stone of 72 lbs.	Near Larissa, Macedonia	January 1706	Paul Lucas
About 1200 stones—one of 120 lbs. Another of 60 lbs.	Near Padua in Italy	In 1510	Carden, Varcit
Another of 59 lbs.	On Mount Vaiser, Provence	November 27th, 1627	Gassendi
Shower of sand for 15 hours	In the Atlantic	April 6th, 1719	Pére la Feuillée
Shower of sulphur	Sodom and Gomorra		Moses
Sulphureous rain	In the duchy of Mansfeld	In 1658	Spangenberg
The same	Copenhagen	In 1646	Olaus Wurmius
Shower of sulphur	Brunswick	October 1721	Siegesber
Ditto of a viscid unknown matter	Ireland	In 1695	Muschenbroeck
Two large stones weighing 20 lbs.	Liponas in Bresse	September 1753	Delalande
A stony mass	Niort, Normandy	In 1750	Delalande
A stone of 7½ lbs.	At Luce in Le Maine	September 13th, 1768	Bachelay
A stone	At Aire in Artois	In 1768	Gurson de Boyaval
A stone	In Le Cotentin	In 1768	Morand
Extensive shower of stones	Environs of Agen	July 24th, 1790	St Amand, Baudin, &c.
About 12 stones	Sienna, Tuscany	July 1794	Earl of Bristol
A large stone of 56 lbs.	Wold-Cottage, Yorkshire	December 13th, 1795	Captain Topham
A stone of about 20 lbs.	Salé, department of the Rhone	March 17th, 1798	Lelievre and De Drée
A stone of 10 lbs.	In Portugal	February 19th, 1796	Southey
Shower of stones	Benares, East Indies	December 19th, 1798	J. Lloyd Williams, Esq.
Shower of stones	At Plann, near Tabor, Bohemia	July 3d, 1753	B. de Born
Mass of iron 70 cubic feet	America	April 5th, 1800	Philosophical Magazine
Mass of ditto, 14 quintals	Abakank, Siberia	Very old	Pallas, Chladni, &c.
Shower of stones	Barboutan, near Roquefort	July 1789	Darcet, jun. Lomet. &c.
Large stone, 260 lbs.	Ensisheim, Upper Rhine	Noxember 7th, 1492	Butenschoen
Two stones, 200 and 300 lbs.	Near Verona	In 1762	Acad. de Bourd.
A stone of 20 lbs.	Sales, near Ville-Franche	March 12th, 1798	De Drée
Several ditto from 10 to 17 lbs.	Near L'Aigle, Normandy	April 26th, 1803	Fourcroy

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Stones usually covered with a black crust.

2. The stony bodies when found are always hot. They commonly bury themselves some depth under ground. Their size differs from a few ounces to several tons. They are usually roundish, and always covered with a black crust. In many cases they smell strongly of sulphur. The black crust, from the analysis of Howard, consists chiefly of oxide of iron.

Their composition.

3. The outer surface of these stones is rough. When broken, they appear of an ash-grey colour, and of a granular texture like a coarse sandstone. When examined with a microscope, four different substances may be discovered, of which the stone is composed: 1st, A number of spherical bodies, varying in size from a pin head to a pea, of a greyish brown colour, opaque, breaking easily in every direction, of a compact texture, capable of scratching glass, and of giving a few feeble sparks with steel. 2d, Fragments of pyrites of an indeterminate shape, of a reddish-yellow colour, granular, and easily reduced to powder. The powder has a black colour. 3d, Grains of iron in the metallic state, scattered like the pyrites through the stone. 4th, The three substances just mentioned are cemented together by a fourth of an earthy consistence, and so soft that all the other substances may be sasily separated by the point of a knife or the nail, and the stone itself crumbled to pieces between the fingers. This cement is of a grey colour *. The proportion and size of these different constituents vary considerably in different specimens; but all of them bear a striking resemblance to each other. Their specific gravity varies from 3.352 to 4.281 †.

* Bournon, *Phil. Trans.* 1802. † Ibid.

Their chemical analysis.

4. From the analysis of Howard, which was conducted with much precision and address, and which has been fully confirmed by Vauquelin and Klaproth, we learn, that the black crust consists of a compound of iron and nickel, partly metallic and partly oxydized. The pyrites consist of iron, nickel, and sulphur. The metallic grains consist of iron, combined with about $\frac{1}{20}$d of its weight of nickel, and the yellow globules are composed of silica, magnesia, iron, and nickel. The Count Bournon observes, that these globules resemble the chrysolite of Werner, and that their chemical analysis corresponds exactly with Klaproth's analysis of that mineral. The earthy cement consists of the very same substances, and nearly in the same proportions as the globular substances. But it will be necessary to exhibit a specimen of some of the analyses as published by the philosophers, to whom we are indebted for them. A stone which fell at Benares in India was analysed by Howard, The pyrites consisted of 2.0 sulphur

10.5 iron
1.0 nickel
2.0 earths and foreign bodies.

15.5

The spherical bodies 50.0 silica
15.0 magnesia
34.0 oxide of iron
2.5 oxide of nickel

101.5

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The earthy cement 48.0 silica
18.0 magnesia
34.0 oxide of iron
2.5 oxide of nickel

102.5

A stone which fell in Yorkshire, deprived as much as possible of its metallic particles, gave Mr Howard from 150 grains

75 silica
37 magnesia
48 oxide of iron
2 oxide of nickel

162

The increase of weight was owing to the oxydizement of the metallic bodies.

Stones which fell at Laigle in France in 1803 yields, by the analysis of Vauquelin and Fourcroy,

54 silica
36 oxide of iron
9 magnesia
3 oxide of nickel
2 sulphur
1 lime

105 *

The celebrated stone which fell at Ensisheim, in Alsace, in 1492, yielded to the same philosophers

* *Phil. Mag.* xvi. 302.

56.0 silica
30.0 oxide of iron
12.0 magnesia
2.4 nickel
3.5 sulphur
1.4 lime

105.3

Conjectures respecting their origin.

5. The experiments of Howard, thus confirmed by others, and supported by the most respectable historical evidence, having demonstrated that these stony bodies really do fall from the heavens, it was natural to expect that various attempts would be made to account for their appearance. But such is the obscurity of the subject, so little progress have we made in the science of meteorology, that no opinion in the slightest degree probable has hitherto been advanced. It was first supposed that the bodies in question had been thrown out of volcanoes; but the immense distance from all volcanoes at which they have been found, and the absence of all similar stones from volcanic productions, render this opinion untenable. Chladni endeavoured to prove that the meteors from which they fell were bodies floating in space, unconnected with any planetary system, attracted by the earth in their progress, and kindled by their rapid motion through the atmosphere. But this opinion is not susceptible of any direct evidence, and can scarcely be believed, one would think, even by Dr Chladni himself. Laplace suggests the probability of their having been thrown off by the volcanoes of the moon: But the meteors which almost always accompany them, and the swiftness of their horizontal motion, militate too strongly against this opinion. The great-

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er number of philosophers consider them, with Mr King and Sir William Hamilton, as concretions actually formed in the atmosphere. This opinion is undoubtedly the most probable of all; but in the present state of our knowledge, it would be absurd to attempt any explanation of the manner in which they are formed. The masses of native iron found in South America, in Siberia, and near Agnam, contain nickel, as has been ascertained by Proust, Howard, and Klaproth, and resemble exactly the iron found in the stones fallen from the atmosphere. We have every reason therefore to ascribe to them the same original; and this accordingly is almost the uniform opinion of philosophers. Klaproth has shewn that real native iron is distinguished from meteoric iron by the absence of nickel.

Upon the whole, we may consider these stony and metallic masses as fragments of fire-balls which have burst in the atmosphere; but the origin and cause of these fire-balls will perhaps for ages baffle all the attempts of philosophers to explain them.

BOOK II.

OF

WATERS.

MANKIND must have observed, very early, that the waters, which exist in such abundance in almost every part of the earth, differ considerably from each other in their taste and transparency, and in their fitness for serving as vehicles for food, and for the various purposes of domestic economy. These differences are occasioned by the foreign bodies which the aqueous fluid holds in solution or suspension; for water is never found native in a state of complete purity. In some cases the quantity of these foreign matters is so minute as to have but little influence on the taste or the other properties of water; but in other cases, the foreign bodies alter its properties altogether, and render it noxious, or medicinal, or unfit for the preparation of food. In the present Book I shall take a general view of the different springs and collections of water; and give an account of their properties and component parts, as far as they have been hitherto ascertained. Now waters may be

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Divisible into three classes.

very conveniently divided into three classes: 1. Waters which may be used for dressing food, and the other purposes of domestic economy to which water is usually applied. These, for want of a better name, may be called *common water*. 2. Sea water. 3. Those waters which have been called *mineral*, in consequence of the notable quantity of mineral substances which they contain.—These three classes of waters shall form the subject of the three following Chapters.

CHAP. I.

OF COMMON WATERS.

Good water is as transparent as crystal, and entirely colourless. It has no smell, and scarcely any taste; and in general the lighter it is, so much the better. If we compare the different waters which are used for the common purposes of life with each other, and judge of them by the above standard, we shall find them to differ considerably from each other, according to the circumstances of their situation. These waters may be reduced under four heads; namely, 1. Rain water; 2. Spring and river water; 3. Well water; 4. Lake water.

Rain water.

1. Rain water, unless when near a town or when collected at the commencement of the rain, possesses the properties of good water in perfection, and is as free

from foreign ingredients as any native water whatever. The substances which it holds in solution are *air*, *carbonic acid*, *carbonat of lime*, and, according to Bergman, it yields some traces of *nitric acid*, and a little *muriat of lime* *. The existence of air in water was first pointed out by Boyle. Scheele has shewn that it is usually either in the state of oxygen, or at least contains an excess of oxygen, and that water absorbs oxygen gas in preference to common air. The quantity of air in good water does not exceed $\frac{1}{18}$th of the bulk. One hundred cubic inches of water contain generally about one cubic inch of carbonic acid gas. It is to the presence of these two elastic fluids that water owes its taste, and many of the good effects which it produces on animals and vegetables. Hence the vapidness of newly boiled water from which these gases are expelled. Snow water, when newly melted, is also destitute of all gaseous bodies †. Hence the reason that fish cannot live in it, as Carradori has ascertained ‡. Hassenfratz, indeed, has endeavoured to prove, that snow water holds oxygen gas in solution; but in all probability the water which he examined had absorbed air from the atmosphere.

Snow water.

The quantity of muriat of lime contained in rain water must be exceedingly minute; as Morveau has ascertained that rain water may be rendered sufficiently pure for chemical purposes by dropping into it a little barytic water, and then exposing it for some time to the atmosphere, and allowing the precipitate formed to deposite. According to that very accurate philosopher,

How purified.

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* Bergman, i. 87. † Ibid. ‡ *Jour. de Phys.* xlviii. 226.

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the rain water which drops from the roofs of houses, after it has rained for some time, contains only a little sulphat of lime, which it has dissolved as it trickled over the slates *.

Spring water.

2. The water of springs is nothing else than rain water, which, gradually filtering through the earth, collects at the bottom of declivities, and makes its way to the surface. It is therefore equally pure with rain water, provided it does not meet with some soluble body or other in its passage through the soil. But as this is almost always the case, we generally find, even in the purest spring water, a little carbonat of lime and common salt, besides the usual proportion of air and carbonic acid gas. Sometimes also it contains muriat of lime or a little carbonat of soda †. Bergman found the springs about Upsal, which are reckoned exceedingly pure, to contain the following foreign bodies:

1. Oxygen gas,	5. Common salt,
2. Carbonic acid,	6. Sulphat of potass,
3. Carbonat of lime,	7. Carbonat of soda,
4. Silica,	8. Muriat of lime.

The whole of these ingredients amounted at an average to 0.00004 parts; and the proportion of each of the solid bodies was as follows:

Carbonat of lime	5.0	Muriat of lime	0.5
Common salt . . .	3.0	Sulphat of potass	0.25
Silica	0.5	Carbonat of soda	0.25

River water.

River waters may be considered as merely a collection of spring and rain water, and therefore are usually

* *Ann. de Chim.* xxiv. 321. † Bergman, i. 88.

possessed of a degree of purity at least equal to these. Indeed when their motion is rapid, and their bed siliceous sand, they are generally purer than spring water; depositing during their motion every thing which was merely mechanically suspended, and retaining nothing more than the usual proportion of air and carbonic acid gas, and a very minute quantity of carbonated lime and common salt. When their bed is clayey, they are usually opal-coloured, in consequence of the particles of clay which they hold in suspension.

Well water.

3. By well water is meant the water which is obtained by digging deep pits, which is not in sufficient quantity to overflow the mouth of the well; but which may be obtained in abundance by pumping. It is essentially the same with spring water, being derived from the very same source; but it is more liable to be impregnated with foreign bodies from the soil, in consequence of its stagnation or slow filtration. Hence the reason that well water is often of that kind which is distinguished by the name of *hard water*, because it does not dissolve soap, and cannot be used for dressing several kinds of food. These properties are owing to the great proportion of earthy salts which it holds in solution. The most common of these salts is sulphat of lime. These earthy salts have the property of decomposing common soap: their acid unites with the alkali of the soap, while the earthy basis forms with the oil a soap not soluble in water, which envelopes the soap and gives it a greasy feel. These waters may be in general cured by dropping into them an alkaline carbonat. Mr Senncbier has shewn that well water usually contains a greater proportion of carbonic acid gas than spring or river water.

Hard waters.

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Water of lakes.

4. The water of lakes is merely a collection of rain water, spring water, and river water, and of course contains precisely the same heterogeneous salts: But it is seldom so transparent as river water, being usually contaminated with the remains of animal and vegetable bodies which have undergone putrefaction in it. For as lake water is often nearly stagnant, it does not oppose the putrefaction of these bodies, but rather promotes it; whereas in river water, which is constantly in motion, no putrefaction takes place. Hence the reason of the slimy appearance and the brownish colour which often distinguishes lake water.

Marsh water contains a still greater proportion of animal and vegetable remains than lake water, because it is altogether stagnant. Moss water is strongly impregnated with those vegetable bodies which constitute mosses, and usually also contains iron.

CHAP. II.

OF SEA WATER.

THE Ocean is the great reservoir of water into which the lakes and rivers empty themselves, and from which is again drawn by evaporation that moisture which, falling in showers of rain, fertilizes the earth, and supplies the waste of the springs and rivers. This constant circulation would naturally dispose one to believe, *a priori*, that the waters of the ocean do not differ much from the waters of rivers and lakes: but nothing would be more erroneous than such a conclusion; for the sea water, as every one knows, differs materially from common water in its taste, specific gravity, and other properties. It contains a much greater proportion of saline matter, particularly of common salt, which is usually extracted from it. Indeed, if the sea were not impregnated with these saline bodies, the putrefaction of the immense mass of animal and vegetable matter which it contains would in a short time prove fatal to the whole inhabitants of the earth.

Quantity of sea water.

The absolute quantity of sea water cannot be ascertained, as its mean depth is unknown. Mr De la Place has demonstrated, that a depth of four leagues is necessary to reconcile the height to which the tides are known to rise in the main ocean with the Newtonian

Book II.

theory of the tides *. If we suppose this to be the mean depth, the quantity of water in the ocean must be immense. Even on the supposition that its mean depth is not greater than the fourth part of a mile, its solid contents (allowing its surface to be three-fourths of that of the superficies of the earth) would be 32,058,939¾ cubic miles.

Its properties.

Sea water has a very disagreeable bitter taste, at least when taken from the surface or near the shore; but when brought up from great depths, its taste is only saline †. Hence we learn that this bitterness is owing to the animal and vegetable bodies with which it is mixed near the surface. Its specific gravity varies from 1.0269 to 1.0285 ‡. It does not freeze till cooled down to 28.5° § of Fahrenheit's scale.

Saline contents.

It has been ascertained by the experiments of different chemists ‖, and especially by those of Bergman, that sea water holds in solution muriat of soda, muriat of magnesia, sulphat of magnesia, and sulphat of lime; besides the animal and vegetable bodies with which it is occasionally contaminated. The average quantity of saline ingredients is $\frac{1}{28}$. Bergman found water taken up from the depth of 60 fathoms, near the Canaries, by Dr Sparrman, to contain $\frac{1}{24}$. Lord Mulgrave found the water at the back of Yarmouth sands to contain about $\frac{1}{17}$ part. Bergman found water taken up from a depth of sixty fathoms to contain only the following salts in the following proportions.

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* *Mem. Par.* 1776, p. 213. † Bergman, i. 180.

‡ Bladh, Kirwan's *Geological Essays*, p. 355.

§ Nairne, *Phil. Trans.* 1776. Part First.

‖ Monnet, Lavoiser, Baumé, &c. have published analyses of sea water.

30.911 common salt
6.222 muriat of magnesia
1.000 sulphat of lime

Mr Lavoisier found 10,000 parts of sea water taken up on the west of Dieppe to contain the following salts:

1375 muriat of soda
256 muriat of lime and magnesia
156 muriat of magnesia
87 lime
84 sulphat of soda and magnesia

1958

or almost $\frac{1}{7}$ of saline contents *; but this proportion is undoubtedly excessive. My analysis gives $\frac{1}{10}$ of saline contents in the water of the Frith of Forth. The salts which I found were the same as those announced by Bergman, sulphat of magnesia excepted, which exists in all the specimens of sea water that I have examined; and the proportion of it is considerable.

In different places.

As far as experiment has gone, the proportion of saline contents does not differ much, whatever be the latitude in which the water of the ocean is examined. Lord Mulgrave, in north latitude 80°, and 60 fathoms under ice, found the saline contents of sea water 0.0354; in latitude 74°, he found them 0.036; in latitude 60° 0.034. Pages found sea water taken up in north latitude 45° and 39° to contain 0.04 of saline contents; and Beaumé obtained by analysis, from water taken up by Pages in north latitude 34° and 14°, exactly the same proportions of saline matter. In southern latitudes

* *Mem. Par.* 1772, as quoted by Kirwan.

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Pages found the following proportions of saline matters:

Latitude.	Saline Matter.
49° 50′	0.0416
46 0	0.045
40 30	0.04
25 54	0.04
20 0	0.039
1 16	0.035

From the experiments made by Bladh on the specific gravity of sea water in different latitudes, it appears that the water contains more salt at the tropics than towards the equator.

Specific gravity of water holding different proportions of salt in solution.

If we were acquainted with the proportion between the saline contents of sea water and its specific gravity, it would be easy in all cases to ascertain the quantity of saline matter merely by taking the specific gravity of the water we wish to examine. This would require a set of experiments on purpose; dissolving in pure water different quantities of the salts contained in sea water in the proportions which they bear to each other, and ascertaining the specific gravity of every such solution. Dr Watson has given us a Table for ascertaining that point, as far as common salt is concerned; and as the salt which he used was not perfectly pure, but contained a mixture of the different salts usually found in the sea, we may consider it as very nearly determining the proportion of saline contents in sea water as far as it goes. This TABLE therefore I shall here insert*.

* Watson's *Chemical Essays*, v. 91.

Proport. of Salt.	Specific Gravity.	Proport. of Salt.	Specific Gravity.	Proport. of Salt.	Specific Gravity.
0	1.000	$\frac{1}{21}$	1.032	$\frac{1}{84}$	1.007
$\frac{1}{2}$	1.206	$\frac{1}{24}$	1.029	$\frac{1}{108}$	1.006
$\frac{1}{4}$	1.160	$\frac{1}{27}$	1.027	$\frac{1}{120}$	1.005
$\frac{1}{5}$	1.121	$\frac{1}{28}$	1.025	$\frac{1}{144}$	1.004
$\frac{1}{6}$	1.107	$\frac{1}{30}$	1.024	$\frac{1}{162}$	1.003
$\frac{1}{7}$	1.096	$\frac{1}{31}$	1.023	$\frac{1}{192}$	1.0029
$\frac{1}{8}$	1.087	$\frac{1}{36}$	1.020	$\frac{1}{250}$	1.0023
$\frac{1}{9}$	1.074	$\frac{1}{39}$	1.019	$\frac{1}{350}$	1.0018
$\frac{1}{12}$	1.059	$\frac{1}{42}$	1.015	$\frac{1}{448}$	1.0017
$\frac{1}{14}$	1.050	$\frac{1}{48}$	1.014	$\frac{1}{512}$	1.0014
$\frac{1}{15}$	1.048	$\frac{1}{54}$	1.013	$\frac{1}{843}$	1.0008
$\frac{1}{16}$	1.045	$\frac{1}{56}$	1.012	$\frac{1}{1024}$	1.0006
$\frac{1}{18}$	1.040	$\frac{1}{72}$	1.009		

This Table was calculated at a temperature between 46° and 55°; but Mr Kirwan has reduced part of it to the temperature of 62°, in order to compare it with the specific gravities of sea water taken at that temperature, or at least reduced to it. The specific gravities, thus altered by Kirwan, are as follows:

Proportion of Salt.	Specific Gravity at 62°.
$\frac{1}{24}$	1.0283
$\frac{1}{25}$	1.0275
$\frac{1}{26}$	1.0270
$\frac{1}{27}$	1.0267
$\frac{1}{28}$	1.0250
$\frac{1}{30}$	1.0233
$\frac{1}{39}$	1.0185
$\frac{1}{44}$	1.0033
$\frac{1}{56}$	1.0105
$\frac{1}{108}$	1.004
$\frac{1}{162}$	1.0023

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This Table will enable us to ascertain the saline contents of sea water in different parts of the Atlantic and Indian Oceans, from the following TABLE of the specific gravity of sea water in different parts of these oceans, constructed by Bladh, and reduced by Kirwan to the temperature of 62° *.

Specific gravity of sea water in different places.

LATITUDE.	LONGITUDE †.	Sp. Gr. at 62°.
North.	East.	
59° 39′	8° 48′	1.0272
57 18	18 48	1.0269
	West.	
57 1	1 22	1.0272
54 00	4 45	1.0271
44 32	2 04	1.0276
	East.	
44 07	1 00	1.0276
40 41	0 30	1.0276
34 40	1 18	1.0280
29 50	0 00	1.0281
	West.	
24 00	2 32	1.0284
18 28	3 24	1.0281
16 36	3 37	1.0277
14 56	3 46	1.0275
10 30	3 49	1.0272
5 50	3 28	1.0274
2 20	3 26	1.0271
1 25	3 30	1.0273
South.		
0 16	3 40	1.0277
5 10	6 00	1.0277
10 00	6 05	1.0285
14 40	7 00	1.0284
20 06	5 30	1.0285
25 45	2 22	1.0281
	East.	
30 25	7 12	1.0279
37 37	68 13	1.0276

* Kirwan's *Geol. Essays*, p. 350. † The Lon. is counted from Teneriffe.

From this Table, compared with the last, we learn, that the ocean contains most salt between south latitude 10° and 20°; the saline contents amounting to rather more than $\frac{1}{24}$. The quantity of salt between north latitude 18° and 34° is rather less than $\frac{1}{24}$: at the equator it is nearly $\frac{1}{25}$. The proportion of salt is least of all in north latitude 57°, where it amounts to little more than $\frac{1}{27}$.

Of the Baltic.

From the experiments of Wilcke, we learn that the Baltic contains much less salt than the ocean; that the proportion of its salt is increased by a west wind, and still more by a north-west wind. The specific gravity of the Baltic water, ascertained by this philosopher under these different circumstances, and reduced by Mr Kirwan to the temperature of 62°, is exhibited in the following TABLE:

Specific Gravity.	
1.0039	Wind at E.
1.0067	Ditto at W.
1.0118	Storm at W.
1.0098	Wind at N.W.

From this Table it appears that the proportion of salt in the Baltic, when an east wind prevails, is only $\frac{1}{1000}$; and that this proportion is doubled by a westerly storm: a proof not only that the saltness of the Baltic is derived from the neighbouring ocean, but that storms have a much greater effect upon the waters of the ocean than has been supposed*. The Euxine and Caspian Seas, if we believe Tournefort, are less salt

* Kirwan's *Geological Essays*, p. 356.

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than the ocean*; but it is probable that the Mediterranean is at least as salt as the Atlantic.

The Dead Sea.

The water of the *Dead Sea* differs exceedingly from sea water. Its specific gravity is 1.2403; and it is saturated with salt, containing no less than 44.4 *per cent.* of saline matter. According to the analysis of Lavoisier, it is composed of

55.60 water
38.15 muriat of lime and of magnesia,
6.25 common salt

100.00†

The water of this lake, therefore, ought to be distinguished from sea-water; and might with propriety be included among *mineral* waters.

* Tournefort's *Voyages*, ii. 410.
† *Mem. Par.* 1778, p. 69.

CHAP. III.

OF MINERAL WATERS.

All waters which are distinguished from common water by a peculiar smell, taste, colour, &c. and which in consequence of these properties cannot be applied to the purposes of domestic economy, have been distinguished by the appellation of *mineral waters*. These occur more or less frequently in different parts of the earth, constituting wells, springs, or fountains; sometimes of the temperature of the soil through which they pass, sometimes warm, and in some cases even at the boiling temperature. Many of these mineral springs attracted the attention of mankind in the earliest ages, and were resorted to by those who laboured under diseases, and employed by them either externally or internally as a medicine. But it was not till towards the end of the 17th century that any attempt was made to detect the ingredients of which these waters were composed, or to discover the substances to which they owed their properties. Mineral waters explained.

Mr Boyle may be considered as the first person who pointed out the method of examining water. He first ascertained the existence of air in it, and pointed out a number of tests, by means of which conjectures might be made concerning the saline bodies which the water Attempts to analyse them.

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examined held in solution. In 1665, Dominic du Clos attempted to examine the different mineral waters in France. He employed almost all the re-agents recommended by Boyle, and likewise added several of his own. In 1680, Hierne published a set of experiments on the mineral waters of Sweden. Soon after various improvements were introduced by Regis, Didier, Burlet, and Homberg; and in 1726 Bouldoc pointed out a method of precipitating several of the saline contents of water by means of alcohol. But it was not till after the discovery of carbonic acid by Dr Black, that any considerable progress was made in ascertaining the composition of mineral waters. That subtile acid which is so often contained in them, and which serves as a solvent to many of the earths and even metallic bodies, had thwarted all the attempts of former chemists to detect the composition of these liquids. Since the discovery of that acid, the analysis of mineral waters has advanced with great rapidity, in consequence chiefly of the admirable dissertation on the analysis of mineral waters published by Bergman in 1778. Since that period much has been done by the labours of Gioanetti, Black, Klaproth, Westrum, Fourcroy, Brezé, Kirwan, and many other eminent chemists. So that notwithstanding the difficulty of the subject, scarcely any branch of chemistry has made greater progress, or is farther advanced than the knowledge of mineral waters.

Substances found in them.

The substances hitherto found in mineral waters amount to about 38, and may be reduced under the four following heads: 1. Air and its component parts, oxygen and azotic gas. 2. Acids. 3. Alkalies and earths. 4. Salts.

I. 1. Air is contained in by far the greater number of mineral waters: its proportion does not exceed $\frac{1}{\frac{1}{2}\frac{1}{8}}$th of the bulk of the water. 1. Air.

2. Oxygen gas was first detected in waters by Scheele. Its quantity is usually inconsiderable; and it is incompatible with the presence of sulphureted hydrogen gas or iron.

3. Azotic gas was first detected in Buxton water by Dr Pearson. Afterwards it was discovered in Harrowgate waters by Dr Garnet, and in those of Lemington Priors by Mr Lambe.

II. The only acids hitherto found in waters, except in combination with a base, are the four following: carbonic, sulphurous, boracic, and sulphureted hydrogen gas. 2. Acids.

1. Carbonic acid was first discovered in Pyrmont water by Dr Brownrigg. It is the most common ingredient in mineral waters, 100 cubic inches of the water generally containing from 6 to 40 cubic inches of this acid gas. According to Westrum, 100 cubic inches of Pyrmont water contain 187 cubic inches of it, or almost double its own bulk.

2. Sulphurous acid has been observed in several of the hot mineral waters in Italy, which are in the neighbourhood of volcanoes.

3. The boracic acid has also been observed in some lakes in Italy.

4. Sulphureted hydrogen gas constitutes the most conspicuous ingredient in those waters which are distinguished by the name of hepatic or sulphureous.

III. The only alkali which has been observed in mi- 3. Alkalies and earths.

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neral waters, uncombined, is soda; and the only earthy bodies are silica and lime.

1. Dr Black detected soda in the hot mineral waters of Geyzer and Rykum in Iceland; but in most other cases the soda is combined with carbonic acid.

2. Silica was first observed in waters by Bergman. It was afterwards detected in those of Geyzer and Rykum by Dr Black, and in those of Carlsbad by Klaproth. Hassenfratz observed it in the waters of Pougues, and Brezé in those of Pu. It has been found also in many other mineral waters.

3. Lime is said to have been found uncombined in some mineral waters; but this has not been proved in a satisfactory manner.

4. Salts.

IV. The only salts hitherto found in mineral waters are the following *sulphats*, *nitrats*, *muriats*, *carbonats*, and *hydrosulphurets*:

1. Sulphat of soda
2. . . . . ammonia
3. . . . . lime
4. . . . . magnesia
5. . . . . alumina
6. . . . . iron
7. . . . . copper
8. Nitrat of potass
9. . . . . lime
10. . . . . magnesia
11. Muriat of potass
12. . . . . soda
13. . . . . ammonia
14. . . . . barytes
15. Muriat of lime
16. . . . . magnesia
17. . . . . alumina
18. . . . . manganese
19. Carbonat of potass
20. . . . . soda
21. . . . . ammonia
22. . . . . lime
23. . . . . magnesia
24. . . . . alumina
25. . . . . iron
26. Hydrosulph. of lime
27. . . . . potass
28. And likewise borax

Of these genera the carbonats and muriats occur by far most commonly, and the nitrats most rarely.

1. Sulphat of soda is not uncommon, especially in those mineral waters which are distinguished by the epithet *saline*.

2. Sulphat of ammonia is found in mineral waters near volcanoes.

3. Sulphat of lime is exceedingly common in water. Its presence seems to have been first detected by Dr Lister in 1682.

4. Sulphat of magnesia is almost constantly an ingredient in those mineral waters which have purgative properties. It was detected in Epsom waters in 1610, and in 1696 Dr Grew published a treatise on it.

5. Alum is sometimes found in mineral waters, but it is exceedingly rare.

6. and 7. Sulphat of iron occurs sometimes in volcanic mineral waters, and has even been observed in other places. But sulphat of copper is only found in the waters which issue from copper mines.

8. Nitre has been found in some springs in Hungary; but it is exceedingly uncommon.

9. Nitrat of lime was first detected in water by Dr Home of Edinburgh in 1756. It is said to occur in some springs in the sandy deserts of Arabia.

10. Nitrat of magnesia is said to have been found in some springs.

11. Muriat of potass is uncommon; but it has lately been discovered in the mineral springs of Uhleaborg in Sweden by Julin.

12. Muriat of soda is so exceedingly common in mineral waters, that hardly a single spring has been analysed without detecting some of it.

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13. Muriat of ammonia is uncommon; but it has been found in some mineral springs in Italy and in Siberia.

14. Muriat of barytes is still more uncommon; but its presence in mineral waters has been announced by Bergman.

15. and 16. Muriats of lime and magnesia are common ingredients.

17. Muriat of alumina has been observed in waters by Dr Withering; but it is very uncommon.

18. Muriat of manganese was mentioned by Bergman as sometimes occurring in mineral waters. It has lately been detected by Lambe in the waters of Lemington Priors; but in an extremely limited proportion.

19. The presence of carbonat of potass in mineral waters has been mentioned by several chemists: if it does occur, it must be in a very small proportion.

20. But carbonat of soda is, perhaps, the most common ingredients of these liquids, if we except common salt and carbonat of lime.

21. Carbonat of ammonia has been discovered in waters; but it is uncommon.

22. Carbonat of lime is found in almost all waters, and is usually held in solution by an excess of acid. It appears from the different experiments of chemists, as stated by Mr Kirwan, and especially from those of Berthollet, that water saturated with carbonic acid is capable of holding in solution 0.002 of carbonat of lime. Now water saturated with carbonic acid at the temperature of 50°, contains very nearly 0.002 of its weight of carbonic acid. Hence it follows that carbonic acid, when present in such quantity as to saturate water, is capable of holding its own weight of carbonat of lime

in solution. Thus we see that 1000 parts by weight of water, when it contains two parts of carbonic acid, is capable of dissolving two parts of carbonat of lime. When the proportion of water is increased, it is capable of holding the carbonat of lime in solution, even when the proportion of carbonic acid united with it is diminished. Thus 24,000 parts of water are capable of holding two parts of carbonat of lime in solution, even when they contain only one part of carbonic acid. The greater the proportion of water, the smaller a proportion of carbonic acid is necessary to keep the lime in solution; and when the water is increased to a certain proportion, no sensible excess of carbonic acid is necessary. It ought to be remarked also, that water, how small a quantity soever of carbonic acid it contains, is capable of holding carbonat of lime in solution, provided the weight of the carbonic acid present exceed that of the lime *. These observations apply equally to the other earthy carbonats held in solution by mineral waters.

23. Carbonat of magnesia is also very common in mineral waters, and is almost always accompanied by carbonat of lime.

24. Carbonat of alumina is said to have been found in waters; but its presence has not been properly ascertained.

25. But carbonat of iron is by no means uncommon; indeed it forms the most remarkable ingredient in those waters which are distinguished by the epithet of *chalybeate.*

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* Kirwan on *Mineral Waters*, p. 15.

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26. and 27. The hydrosulphurets of lime and of soda have been frequently detected in those waters which are called sulphureous or hepatic.

28. Borax exists in some lakes in Persia and Thibet; but the nature of these waters has not been ascertained *.

5. Vegetable and animal matters.

Besides these substances, certain vegetable and animal matters have been occasionally observed in mineral waters. But in most cases these are rather to be considered in the light of accidental mixtures than of real component parts of the waters in which they occur.

From the above enumeration, we are enabled to form a pretty accurate idea of the substances which occur in mineral waters; but this is by no means sufficient to make us acquainted with these liquids. No mineral water contains all of these substances. Seldom are there more than five or six of them present together, and hardly ever do they exceed the number of eight or ten. The proportion, too, in which they enter into mineral waters is generally small, and in many cases extremely so. Now in order to understand the nature of mineral waters, it is necessary to know the substances which most usually associate together, and the proportion in which they commonly associate. In the greater part of mineral waters there is usually some substance present which, from its greater proportion or its greater activity, stamps, as it were, the character of the water, and gives it those properties by which it is most readily distinguished. This substance of course claims the greatest attention while the other bodies which en-

* Kirwan on *Mineral Waters*, p. 8, &c.

ter in a smaller proportion may vary or even be absent altogether, without producing any sensible change in the nature of the water. This circumstance enables us to divide mineral waters into classes, distinguished by the peculiar substance which predominates in each. Accordingly they have been divided into four classes; namely,

Mineral waters divided into four classes.

1. Acidulous,
2. Chalybeate,
3. Hepatic,
4. Saline.

Let us take a view of each of these classes.

1. The acidulous waters contain a considerable proportion of carbonic acid. They are easily distinguished by their acid taste, and by their sparkling like champaign wine when poured into a glass. They contain almost constantly some common salt, and in general also a greater or smaller proportion of the earthy carbonats.

1. Acidulous.

2. The chalybeate waters contain a portion of iron, and are easily distinguished by the property which they have of striking a black with the tincture of nutgalls. The iron is usually held in solution by carbonic acid. It very often happens that this acid is in excess; in which case the waters are not only chalybeate but acidulous. This is the case with the waters of Spa and Pyrmont. In some instances the iron is in the state of a sulphat; but this is uncommon. Waters containing the sulphat of iron may be readily distinguished by the property which they have of continuing to strike a black with tincture of nutgalls even after being boiled and filtered; whereas boiling decomposes the carbonat of iron, and causes its base to precipitate.

2. Chalybeate.

3. The hepatic or sulphureous waters are those which contain sulphureted hydrogen gas. These waters are

3. Hepatic.

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easily distinguished by the odour of sulphureted hydrogen gas which they exhale, and by the property which they have of blackening silver and lead. The nature of the waters belonging to this class long puzzled chemists. Though they often deposite sulphur spontaneously, yet no sulphur could be artificially separated from them. The secret was at last discovered by Bergman. These waters are of two kinds: in the first the sulphureted hydrogen is uncombined; in the second it is united to lime or an alkali. They are frequently also impregnated with carbonic acid, and usually contain some muriats or sulphats.

4. Saline.

4. Saline waters are those which contain only salts in solution, without iron or carbonic acid in excess. They may be distinguished into four different orders. The waters belonging to the first order contain salts whose base is lime, and generally either the carbonat or the sulphat. They are known by the name of hard waters, and have but a slight disagreeable taste. The waters belonging to the second order are those in which common salt predominates. They are readily recognized by their salt taste, and like sea water usually contain some magnesian and calcareous salts. The waters of the third order contain sulphat of magnesia. They have a bitter taste and are purgative. Finally, the waters of the fourth order are alkaline, containing carbonat of soda. They are easily distinguished by the property which they have of tinging vegetable blues green.

Such is a short view of the different classes of mineral waters. A particular description of each particular spring would be inconsistent with the plan of this work.*

* The reader will find an accurate account of the properties and con-

But a pretty accurate notion may be formed of the salts which most commonly associate, and of the proportions of each, from the following TABLE, which exhibits a synoptical view of the component parts of a considerable number of mineral waters as analysed by different chemists.

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stituents of the most celebrated mineral springs, both British and foreign, in Dr Saunders's *Treatise on the Chemical History and Medical Powers of the most celebrated mineral waters.* From this excellent work I have borrowed several of the analyses which appear in the ensuing Table in the text.

	Water.	Gases. Cubic Inches. Oyxgen	Carbonic acid.	Sulph. hydr.	Azotic	Carbonats of Soda.	Lime.	Mag.	Iron.	Muriats of Soda.	Lime.	Mag.	Pot-ass.	Sulphats of Soda.	Lime.	Mag.	Silica.	Alumina.	Resin.
Seltzer[a] . . .	8949	.435	13.068	—	—	5.22	78.3	6.32	—	13.74	—	—	—	—	—	—	—	—	—
Spa[a]	8933	—	9.8	—	—	1.85	1.85	4.35	0.70	0.21	—	—	—	—	—	—	—	—	—
Pyrmont[a] . .	8950	—	19.6	—	—	—	4.3	9.8	0.70	1.7	—	—	—	—	8 38	5.44	—	—	—
Aix la Chap[a]	8940	—	—	13.06	—	15.25	5.98	—	—	6.21	—	—	—	—	—	—	—	—	—
Medvi[a] . . .	8933	—	6.53	8.71	—	—	—	—	0.92	—	0.11	—	—	—	—	—	—	—	—
Carlsbad[b] .	253.0	—	50.	—	—	38.5	12.5	—	0.1¼	32.5	—	—	—	66.75	—	—	2.25	—	—
Lem. Priors[c]	5816	—	.5	—	3.5	—	—	—	.75	430.	—	11 5	—	15.2	11 2.	—	—	—	—
Pouges[d] . .	9216	—	16.7	—	—	10 4	12.4	1.2	—	2.2	—	—	—	—	—	—	3.2	0.35	—
Enghien[e] . .	92160	—	18 5	70.0	—	—	21.4	1.35	—	2.4	—	8.0	—	—	33.3	15.8	—	—	—
Luf	36864	—	5.	2.	—	—	10.22	—	—	36.74	9.25	—	—	—	14.03	—	0 23	—	—
Geyzer[g] . .	10000	—	—	—	—	0.95*	—	—	—	2.46	—	—	—	1.46	—	—	5.4	0.48	—
Uhleaborg[h]	42250	—	10.	—	—	—	1.9	—	1.2	5.7	—	—	1	—	0.8	—	1.7	—	—
Tepliszi[i] . . .	22540	—	—	—	—	13.25	16.5	—	32.5	61.3	28.5	—	—	—	—	—	15.1	—	—
Kilburn[k] . .	138240	—	34.	36.	—	—	2.4	1.25	.3⅛	6.0	.6	12.8	—	28.2	13.0	91.0	—	—	.6
Bristol[l] . . .	103643	3.	30.	—	—	—	13.5	—	—	4.	—	7.25	—	11.25	11.75	—	—	—	—
Tunbridge[m]	103643	1.4	10.6	—	4.	—	—	—	1.	0.5	—	2.25	—	—	1.25	—	—	—	—
Cheltenham[n]	103643	—	30.368	—	15.	—	—	—	5.	5.	—	25.†	—	480.‡	40.	—	—	—	—
Harrogate[o].	103643	—	8.	19.	7.	—	18.5	5.5	—	615.5	13.	91.	—	—	—	10.5	—	—	—
Moffat° . . .	103643	—	1.	10.	4.	—	—	—	—	3.6	—	—	—	—	—	—	—	—	—

a Bergman. b Klaproth. c Lambe, *Manch.* v. 174. d Hassenfratz, *Ann. de Chim.* i. 81. e Fourcroy, Ibid. vi. 172. f Brezé, Ib. x. 44.
g Black. * Pure Soda. h Julin, Crell's *Annals*, 1797, ii. 373. i Jahn, Ibid. i. 331. k Schmeisser, *Phil. Trans.* lxxxii. 127.
l Dr Carrick, Saunders on *Miner. Waters*, p. 118. m Dr Babington, Ib. p. 241. n Fothergill, Ibid. o Garnet, Ibid. p. 524. and 335.
† And sulphat of magnesia. ‡ And corbonat.

CHAP. IV.

OF THE METHOD OF ANALYSING WATERS.

The analysis of waters, or the art of ascertaining the different substances which they hold in solution, and of determining the proportion of these substances, is one of the most difficult things in chemistry. The difficulty arises, not only from the diversity of the bodies which occur in waters, but from the very minute quantities of some of the ingredients. Though many attempts had been made to analyse particular waters, and several of these were remarkably well conducted, no general mode of analysis was known till Bergman published his Treatise on Mineral Waters in 1778. This admirable tract carried the subject all at once to a very high degree of perfection. The Bergmannian method has been followed by succeeding chemists, to whom we are indebted not only for a great number of very accurate analyses of mineral waters, but likewise for several improvements in the mode of conducting the analysis. Mr Kirwan has in 1799 published an Essay on the general analysis of waters, no less valuable than that of Bergman; containing all that has hitherto been done on the subject, and enriched by the numerous experiments of Mr Kirwan himself, which are equally important and well conducted. Mr Kirwan has given a new method of analysis, which will probably be adopted hereafter; not

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only because it is shorter and easier than the Bergmannian, but because it is susceptible of a greater degree of accuracy. I propose in this Chapter to give an account of this method.

The analysis of waters resolves itself into two different branches: 1. The method of ascertaining all the different bodies contained in the water which we are examining. 2. The method of determining the exact proportion of each of these ingredients. These two branches form the subject of the two following Sections.

SECT. I.

METHOD OF DETERMINING THE INGREDIENTS OF WATERS.

THE different bodies which are dissolved and combined in water, are discovered by the addition of certain substances to the water which is subjected to examination. The consequence of the addition is some change in the appearance of the water; and this change indicates the presence or the absence of the bodies suspected. The substances thus employed are distinguished by the name of *tests*, and are the instruments by means of which the analysis of water is accomplished. They were first introduced into chemistry by Boyle, and were gradually increased by succeeding chemists: but Bergman was the first who ascertained with precision the degree of confidence which can be placed in the different tests. They still continued rather uncertain and precarious, till Mr Kirwan shewed how they might be combined

Tests

and arranged in such a manner as to give certain and precise indications whether or not any particular substance constitutes a component part of water. Let us consider by what means the presence or the absence of all the different substances which occur in waters may be ascertained. Chap. IV.

I. The gaseous bodies contained in water are obtained by boiling it in a retort luted to a pneumatic apparatus. The method of separating and examining these different bodies shall be described in the next Section. For gases,

II. The presence of *carbonic acid*, not combined with a base, or combined in excess, may be detected by the following tests: 1. Lime water occasions a precipitate soluble with effervescence in muriatic acid. 2. The infusion of litmus is *reddened*; but the red colour gradually disappears, and may be again restored by the addition of more of the mineral water *. 3. When boiled it loses the property of reddening the infusion of litmus. Carbonic acid,

III. The mineral acids when present, uncombined in water, give the infusion of litmus a permanent red, even though the water has been boiled. Bergman has shewn that paper, stained with litmus, is reddened when dipt into water containing $\frac{1}{15121}$ of sulphuric acid. Mineral acids,

IV. Water containing sulphureted hydrogen gas is distinguished by the following properties: 1. It exhales the peculiar odour of sulphureted hydrogen gas. 2. It Sulphureted hydrogen,

* When the carbonic acid is uncombined with a baze, it reddens the infusion of litmus, though it amounts to no more than one-sixteenth of the bulk of the water which contains it. When it is combined in excess with a base, it must amount to one-sixth of the bulk of the water to produce that effect.—See Kirwan on *Mineral Waters*, p. 35.

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reddens the infusion of litmus fugaciously. 3. It blackens paper dipt into a solution of lead, and precipitates the nitrat of silver black or brown.

Alkaline and earthy carbonats,

V. Alkalies, and *alkaline* and *earthy carbonats*, are distinguished by the following tests: 1. The infusion of turmeric, or paper stained with turmeric, is rendered *brown* by alkalies, or reddish-brown if the quantity be minute. This change is produced when the soda in water amounts only to $\frac{1}{2217}$ part *. 2. Paper stained with Brazil wood, or the infusion of Brazil wood, is rendered blue: but this change is produced also by the alkaline and earthy carbonats. Bergman ascertained that water containing $\frac{1}{9945}$ part of carbonat of soda renders paper stained with Brazil wood blue †. 3. Litmus paper reddened by vinegar is restored to its original blue colour. This change is produced by the alkaline and earthy carbonats also. 4. When these changes are fugacious, we may conclude that the alkali is ammonia.

Fixed alkalies,

VI. Fixed alkalies exist in water which occasions a precipitate with muriat of magnesia after being boiled. Volatile alkali may be distinguished by the smell, or it may be obtained in the receiver by distilling a portion of the water gently, and then it may be distinguished by the above tests.

Earthy and metallic carbonats,

VII. Earthy and metallic carbonats are precipitated

* The same change is produced by lime-water; but pure lime very seldom indeed occurs in mineral waters. It is needless to observe, that the alkalies produce the same effect on turmeric, whether they be pure or in the state of carbonats. The earthy carbonats have no effect on turmeric.

† Sulphat of lime likewise renders Brazil wood blue.

by boiling the water containing them; except carbonat of magnesia, which is only precipitated imperfectly. Chap. IV.

VIII. Iron is discovered by the following tests: 1. The addition of tincture of nutgalls gives water containing iron a purple or black colour. This test indicates the presence of a very minute portion of iron. If the tincture has no effect upon the water after boiling, though it colours it before, the iron is in the state of a carbonat. The following observations of Westrum on colour which iron gives to nutgalls, as modified by other bodies, deserve attention. Iron,

A violet indicates an alkaline carbonat or earthy salt.

Dark purple indicates other alkaline salts.

Purplish red indicates sulphureted hydrogen gas *.

Whitish and then black indicates sulphat of lime.

2. The prussian alkali occasions a blue precipitate in water containing iron. If an alkali be present, the blue precipitate does not appear unless the alkali be saturated with an acid

IX. Sulphuric acid exists in waters which form a precipitate with the following saline solutions: Sulphuric acid,

1. Muriat, nitrat, or acetat of barytes
2. - - - - - - - - - strontian
3. - - - - - - - - - lime
4. Nitrat or acetat of lead.

Of these the most powerful by far is muriat of barytes, which is capable of detecting the presence of sulphuric acid uncombined, when it does not exceed the millionth part of the water. Acetat of lead is next in point of power. The muriats are more powerful than the nitrats. The calcareous salts are least powerful. All

* Or rather manganese, according to Kirwan.

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these tests are capable of indicating a much smaller proportion of uncombined sulphuric acid than when it is combined with a base *. To render muriat of barytes a certain test of sulphuric acid, the following precautions must be observed: 1. The muriat must be diluted. 2. The alkalies, or alkaline carbonats, if the water contain any, must be previously saturated with muriatic acid. 3. The precipitate must be insoluble in muriatic acid. 4. If boracic acid be suspected, muriat of strontian must be tried, which is not precipitated by boracic acid. 5. The hydrosulphurets precipitate barytic solutions, but their presence is easily discovered by the smell.

Muriatic acid,

X. Muriatic acid is detected by nitrat of silver, which occasions a white precipitate, or a cloud in water containing an exceedingly minute portion of this acid. To render this test certain, the following precautions are necessary: 1. The alkalies or carbonats must be previously saturated with nitric acid. 2. Sulphuric acid, if any be present, must be previously removed by means of nitrat of barytes. 3. The precipitate must be insoluble in nitric acid.

Boracic acid,

XI. Boracic acid is detected by means of acetat of lead, with which it forms a precipitate insoluble in acetic acid. But to render this test certain, the alkalies and earths must be previously saturated with acetic acid, and the sulphuric and muriatic acids removed by means of acetat of strontian and acetat of silver.

Barytes,

XII. Barytes is detected by the insoluble white precipitate which it forms with diluted sulphuric acid.

* Kirwan on *Mineral Waters*, p. 65.

XIII. Lime is detected by means of oxalic acid, which occasions a white precipitate in water, containing a very minute proportion of this earth. To render this test decisive, the following precautions are necessary: 1. The mineral acids, if any be present, must be previously saturated with an alkali. 2. Barytes, if any be present, must be previously removed by means of sulphuric acid. 3. Oxalic acid precipitates magnesia but very slowly, whereas it precipitates lime instantly. Lime,

XIV. Magnesia and alumina. The presence of these earths is ascertained by the following tests: 1. Pure ammonia precipitates them both, and no other earth, provided the carbonic acid has been previously separated by a mineral alkali and boiling. 2. Lime-water precipitates only these two earths, provided the carbonic acid be previously removed, and the sulphuric acid also, by means of nitrat of barytes. Magnesia and alumina.

The alumina may be separated from the magnesia after both have been precipitated together, either by boiling the precipitate in pure potass, which dissolves the alumina and leaves the magnesia; or the precipitate may be dissolved in muriatic acid precipitated by an alkaline carbonat, dried in the temperature of a 100°, and then exposed to the action of diluted muriatic acid, which dissolves the magnesia without touching the alumina.

XV. Silica may be ascertained by evaporating a portion of the water to dryness, and redissolving the precipitate in muriatic acid. The silica remains behind undissolved. Silica.

Such is the method of detecting the different substances commonly found in waters. But as these different substances are almost always combined together,

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so as to constitute particular salts, it is not sufficient to know in general what the substances are which are found in the water we are examining; we must know also in what manner they are combined. Thus it is not sufficient to know that lime forms an ingredient in a particular water, we must know also the acid with which it is united. Mr Kirwan first pointed out how to accomplish this difficult task by means of tests. Let us take a short view of his method.

Sulphats.

I. To ascertain the presence of the different sulphats.

The sulphats which occur in water are seven; but one of these, namely, *sulphat of copper*, is so uncommon, that it may be excluded altogether. The same remark applies to sulphat of ammonia. It is almost unnecessary to observe, that no sulphat need be looked for unless both its acid and base have been previously detected in the water.

1 Alkaline.

1. Sulphat of soda may be detected by the following method: Free the water to be examined of all earthy sulphats by evaporating it to one half, and adding lime-water as long as any precipitate appears. By this means the earths will all be precipitated except lime, and the only remaining earthy sulphat will be sulphat of lime, which will be separated by evaporating the liquid till it becomes concentrated, and then dropping into it a little alcohol, and after filtration adding a little oxalic acid.

With the water thus purified, mix solution of lime. If a precipitate appears either immediately or on the addition of a little alcohol, it is a proof that sulphat of potass or of soda is present. Which of the two may be determined by mixing some of the purified water

with acetat of barytes. Sulphat of barytes precipitates. Filter and evaporate to dryness. Digest the residuum in alcohol. It will dissolve the alkaline acetat. Evaporate to dryness, and the dry salt will deliquesce if it be acetat of potass, but effloresce if it be acetat of soda.

2. Sulphat of lime may be detected by evaporating the water suspected to contain it to a few ounces. A precipitate appears, which, if it be sulphat of lime, is soluble in 500 parts of water; and the solution affords a precipitate with the muriat of barytes, oxalic acid, carbonat of magnesia, and with alcohol. 2. Calcarous.

3. Alum may be detected by mixing carbonat of lime with the water suspected to contain it. If a precipitate appears it indicates the presence of alum, or at least of sulphat of alumina; provided the water contains no muriat of barytes or metallic sulphats. The first of these salts is incompatible with alum. The second may be removed by the alkaline prussiats. When a precipitate is produced in water by muriat of lime, carbonat of lime, and muriat of magnesia, we may conclude that it contains alum or sulphat of alumina. 3. Alum.

4. Sulphat of magnesia may be detected by means of hydrosulphuret of strontian, which occasions an immediate precipitate with this salt and with no other; provided the water be previously deprived of alum, if any be present, by means of carbonat of lime, and provided also that it contains no uncombined acid, nor even carbonic acid. 4. Magnesian.

5. Sulphat of iron is precipitated from water by alcohol, and then it may be easily recognised by its properties. 5. Of iron.

II. To ascertain the presence of the different muriats. Muriats.

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The muriats found in waters amount to eight or to nine, if muriat of iron be included. The most common by far is muriat of soda.

1. Alkaline. 1. Muriat of soda and of potass may be detected by the following method: Separate the sulphuric acid by alcohol and nitrat of barytes. Decompose the earthy nitrats and muriats by adding sulphuric acid. Expel the excess of muriatic and nitric acids by heat. Separate the sulphats thus formed by alcohol and barytes water. The water thus purified can contain nothing but alkaline nitrats and muriats. If it forms a precipitate with acetat of silver, we may conclude that it contains muriat of soda or of potass. To ascertain which, evaporate the liquid thus precipitated to dryness; dissolve the acetat in alcohol. Evaporate to dryness. The salt will deliquesce if it be acetat of potass, but effloresce if it be acetat of soda.

2. Barytic. 2. Muriat of barytes may be detected by sulphuric acid, as it is the only barytic salt hitherto found in waters.

3. Calcareous. 3. Muriat of lime may be detected by the following method: Free the water of sulphat of lime and other sulphats, by evaporating it to a few ounces, mixing it with spirit of wine, and adding last of all nitrat of barytes as long as any precipitate appears. Filter off the water, evaporate to dryness, treat the dry mass with alcohol. Evaporate the alcohol to dryness, and dissolve the residuum in water. If this solution gives a precipitate with acetat of silver and oxalic acid, it *may* contain muriat of lime. It must contain it in that case, if, after being treated with carbonat of lime, it gives no precipitate with ammonia. If it does, separate the lime by means of oxalic acid, filter and distil

with a gentle heat. If the liquid in the receiver gives a precipitate with nitrat of silver, muriat of lime existed in the water.

4. Muriat of magnesia may be detected by separating all the sulphuric acid by means of nitrat of barytes. Filter, evaporate to dryness, and treat the dry mass with alcohol. Evaporate the alcohol solution to dryness, and dissolve the residuum in water. The muriat of magnesia, if the water contained any, will be found in this solution. Let us suppose that, by the tests formerly described, the presence of muriatic acid and of magnesia in this solution has been ascertained. In that case, if carbonat of lime affords no precipitate, and if sulphuric acid and evaporation, together with the addition of a little alcohol, occasion no precipitate, the solution contains only muriat of magnesia. If these tests give precipitates, we must separate the lime which is present by sulphuric acid and spirit of wine, and distil off the acid with which it was combined. Then the magnesia is to be separated by the oxalic acid and alcohol; and the acid with which it was united is to be distilled off. If the liquid in the retort gives a precipitate with nitrat of silver, the water contains muriat of magnesia. 4. Magnesian.

5. Muriat of alumina may be discovered by saturating the water, if it contain an excess of alkali, with nitric acid, and separating the sulphuric acid by means of nitrat of barytes. If the liquid thus purified gives a precipitate with carbonat of lime, it contains muriat of alumina. The muriat of iron or of manganese, if any be present, is also decomposed, and the iron precipitated by this salt. The precipitate may be dissolved in muriatic acid, and the alumina, iron, and manganese, 5. Aluminous.

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if they be present, may be separated by the rules laid down in the next Book.

Nitrats.

III. To ascertain the presence of the different nitrats. The nitrats but seldom occur in waters; when they do, they may be detected by the following rules:

Alkaline.

1. Alkaline nitrats may be detected by freeing the water examined from sulphuric acid by means of acetat of barytes, and from muriatic acid by acetat of silver. Evaporate the filtered liquid, and treat the dry mass with alcohol; what the alcohol leaves can consist only of the alkaline nitrats and acetat of lime. Dissolve it in water. If carbonat of magnesia occasions a precipitate, lime is present. Separate the lime by means of carbonat of magnesia. Filter and evaporate to dryness, and treat the dried mass with alcohol. The alcohol now leaves only the alkaline nitrats, which may be easily recognised, and distinguished by their respective properties.

2. Calcareous.

2. Nitrat of lime. To detect this salt, concentrate the water, and mix it with alcohol to separate the sulphats. Filter and distil off the alcohol; then separate the muriatic acid by acetat of silver. Filter, evaporate to dryness, and dissolve the residuum in alcohol. Evaporate to dryness, and dissolve the dry mass in water. If this last solution indicates the presence of lime by the usual tests, the water contained nitrat of lime.

3. Magnesian.

3. To detect nitrat of magnesia, the water is to be freed from sulphats and muriats exactly as described in the last paragraph. The liquid thus purified is to be evaporated to dryness, and the residuum treated with alcohol. The alcohol solution is to be evaporated to dryness, and the dry mass dissolved in water. To this solution potass is to be added as long as any preci-

pitate appears. The solution, filtered, and again evaporated to dryness, is to be treated with alcohol. If it leaves a residuum consisting of nitre (the only residuum which it can leave), the water contained nitrat of magnesia.

Such are the methods by which the presence of the different saline contents of waters may be ascertained. The labour of analysis may be considerably shortened, by observing that the following salts are incompatible with each other, and cannot exist together in water except in very minute proportions*.

Incompatible salts.

Salts.	Incompatible with
1. Fixed alkaline sulphats	Nitrats of lime and magnesia, Muriats of lime and magnesia.
2. Sulphat of lime	Alkalies, Carbonat of magnesia, Muriat of barytes.
3. Alum	Alkalies, Muriat of barytes, Nitrat, muriat, carbonat of lime, Carbonat of magnesia.
4. Sulphat of magnesia	Alkalies, Muriat of barytes, Nitrat and muriat of lime.
5. Sulphat of iron	Alkalies, Muriat of barytes, Earthy carbonats.
6. Muriat of barytes	Sulphats, Alkaline carbonats, Earthy carbonats.

* See Kirwan on *Mineral Waters*, passim.

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7. Muriat of lime	Sulphats, except of lime; Alkaline carbonats, Carbonat of magnesia.
8. Muriat of magnesia	Alkaline carbonats, Alkaline sulphats.
9. Nitrat of lime	Alkaline carbonats, Carb. of magn. and alumina; Sulphats, except of lime.

Besides the substances above described, there is sometimes found in water a quantity of bitumen combined with alkali, and in the state of soap. In such waters acids occasion a coagulation; and the coagulum collected on a filter discovers its bituminous nature by its combustibility.

Water also sometimes contains *extractive matter;* the presence of which may be detected by means of nitrat of silver. The water suspected to contain it must be freed from sulphuric and nitric acid by means of nitrat of lead. After this, if it gives a brown precipitate with nitrat of silver, we may conclude that extractive matter is present *.

* Westrum.

SECT. II.

METHOD OF DETERMINING THE PROPORTION OF THE INGREDIENTS.

THE proportion of saline ingredients, held in solution by any water, may be in some measure estimated from its specific gravity. The lighter a water is, the less saline matter does it contain; and, on the other hand, the heavier it is, the greater is the proportion of saline contents. Mr Kirwan has pointed out a very ingenious method of estimating the saline contents of a mineral water whose specific gravity is known; so that the error does not exceed one or two parts in the hundred. The method is this: Subtract the specific gravity of pure water from the specific gravity of the mineral water examined (both expressed in whole numbers), and multiply the remainder by 1.4. The product is the saline contents in a quantity of the water denoted by the number employed to indicate the specific gravity of distilled water. Thus let the water be of the specific gravity 1.079, or in whole numbers 1079. Then the specific gravity of distilled water will be 1000. And $1079 - 1000 \times 1.4 = 110.6 =$ saline contents in 1000 parts of the water in question; and consequently 11.06 in 100 parts of the same water*. This formula will often be of considerable use, as it serves as a kind of

Formula for finding the saline contents of water.

* Kirwan on *Mineral Waters*, p. 145.

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standard to which we may compare our analysis. The saline contents indicated by it are supposed to be freed from their water of crystallization; in which state only they ought to be considered, as Mr Kirwan has very properly observed, when we speak of the saline contents of a mineral water.

Having by this formula ascertained pretty nearly the proportion of saline contents in the water examined, and having by the tests described in the last Section determined the particular substances which exist in it, let us now proceed to ascertain the proportion of each of these ingredients.

To estimate the gaseous bodies.

I. The different aerial fluids ought to be first separated and estimated. For this purpose a retort ought to be filled two-thirds with the water, and connected with a jar full of mercury, standing over a mercurial trough. Let the water be made to boil for a quarter of an hour. The aerial fluids will pass over into the jar. When the apparatus is cool, the quantity of air expelled from the water may be determined either by bringing the mercury within and without the jar to a level; or if that cannot be done, by reducing the air to the proper density by the formulas given in the first Chapter of the last Book. The air of the retort ought to be carefully subtracted, and the jar must be divided into cubic inches and tenths.

The only gaseous bodies contained in water are common air, oxygen gas, azotic gas, carbonic acid, sulphureted hydrogen gas, and sulphurous acid. The last two never exist in water together. The presence of either of them must be ascertained previously by the application of the proper tests. If sulphureted hydrogen gas be present, it will be mixed with the air contained

in the glass jar, and must be separated before that air be examined. For this purpose, the jar must be carried into a tub of warm water, and nitric acid introduced, which will absorb the sulphureted hydrogen. The residuum is then to be again put into a mercurial jar and examined.

If the water contain sulphurous acid, this previous step is not necessary. Introduce into the air a solution of pure potass, and agitate the whole gently. The carbonic acid and sulphurous acid gas will be absorbed, and leave the other gases. Estimate the bulk of this residuum; this, subtracted from the bulk of the whole, will give the bulk of the carbonic acid and sulphurous acids absorbed.

Evaporate the potass slowly nearly to dryness, and leave it exposed to the atmosphere. Sulphat of potass will be formed, which may be separated by dissolving the carbonat of potass by means of diluted muriatic acid and filtering the solution. 100 grains of sulphat of potass indicate 30 grains of sulphurous acid, or 42.72 cubic inches of that acid in the state of gas. The bulk of sulphurous acid gas ascertained by this method, subtracted from the bulk of the gas absorbed by the potass, gives the bulk of the carbonic acid gas. Now 100 cubic inches of carbonic acid, at the temperature of 60° and barometer 30 inches, weigh 46.393 grains. Hence it is easy to ascertain its weight.

The air which remains after the separation of the carbonic acid gas is to be examined by the different eudiometrical methods described in the last Book.

When a water contains sulphureted hydrogen gas, the bulk of this gas is to be ascertained in the following manner: Fill three-fourths of a jar with the water to

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be examined, and invert it in a water trough, and introduce a little nitrous gas. This gas, mixing with the air in the upper part of the jar, will form nitrous acid, which will render the water turbid, by decomposing the sulphureted hydrogen and precipitating sulphur. Continue to add nitrous gas at intervals as long as red fumes appear, then turn up the jar and blow out the air. If the hepatic smell continues, repeat this process. The sulphur precipitated indicates the proportion of hepatic gas in the water; one grain of sulphur indicating the presence of 3.33 cubic inches of that gas.

To estimate the earthy carbonats.

II. After having estimated the gaseous bodies, the next step is to ascertain the proportions of the earthy carbonats. For this purpose it is necessary to deprive the water of its sulphureted hydrogen, if it contains any. This may be done, either by exposing it to the air for a considerable time, or by treating it with litharge. A sufficient quantity of the water thus purified (if necessary) is to be boiled for a quarter of an hour, and filtered when cool. The earthy carbonats remain on the filter.

The precipitate thus obtained may be carbonat of lime, of magnesia, of iron, of alumina; or even sulphat of lime. Let us suppose all of these substances to be present together. Treat the mixture with diluted muriatic acid, which will dissolve the whole except the alumina and sulphat of lime. Dry this residuum in a red heat, and note the weight. Then boil it in carbonat of soda: saturate the soda with muriatic acid, and boil the mixture for half an hour. Carbonat of lime and alumina precipitate. Dry this precipitate, and treat it with acetic acid. The lime will be dissolved and the alumina will remain. Dry it and weigh it. Its weight

subtracted from the original weight gives the proportion of sulphat of lime.

The muriatic solution contains lime, magnesia, and iron. Add ammonia as long as a reddish precipitate appears. The iron and part of the magnesia are thus separated. Dry the precipitate, and expose it to the air for some time in a heat of 200° ; then treat it with acetic acid to dissolve the magnesia, which solution is to be added to the muriatic solution. The iron is to be redissolved in muriatic acid, precipitated by an alkaline carbonat, dried, and weighed.

Add sulphuric acid to the muriatic solution as long as any precipitate appears ; then heat the solution and concentrate. Heat the sulphat of lime thus obtained to redness, and weigh it. 100 grains of it are equivalent to 70 of carbonat of lime dried. Precipitate the magnesia by means of carbonat of soda. Dry it and weigh it. But as part remains in solution, evaporate to dryness, and wash the residuum with a sufficient quantity of distilled water to dissolve the muriat of soda and the sulphat of lime, if any be still present. What remains behind is carbonat of magnesia. Weigh it, and add its weight to the former. The sulphat of lime, if any, must also be separated and weighed.

Estimation of the mineral acids,

III. Let us now consider the method of ascertaining the proportion of mineral acids or alkalies, if any be present uncombined. The acids which may be present (omitting the gaseous) are the sulphuric, muriatic, and boracic.

1. The proportion of sulphuric acid is easily determined. Saturate it with barytes water, and ignite the precipitate. 100 grains of sulphat of barytes thus formed indicate 23.5 of real sulphuric acid.

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2. Saturate the muriatic acid with barytes water, and then precipitate the barytes by sulphuric acid. One hundred parts of the ignited precipitate are equivalent to 21 grains of real muriatic acid.

3. Precipitate the boracic acid by means of acetat of lead. Decompose the borat of lead by boiling it in sulphuric acid. Evaporate to dryness. Dissolve the boracic acid in alcohol, and evaporate the solution; the acid left behind may be weighed.

And alkaline carbonats.

4. To estimate the proportion of alkaline carbonat present in a water containing it, saturate it with sulphuric acid, and note the weight of real acid necessary. Now 100 grains of real sulphuric acid saturate 121.48 potass, and 78.32 soda.

To estimate sulphats.

IV. Let us now consider the method of ascertaining the proportion of the different sulphats. These are six in number; the alkaline sulphats, and those of lime, alumina, magnesia, and iron.

1. Alkaline,

1. The alkaline sulphats may be estimated by precipitating their acid by means of nitrat of barytes, having previously freed the water of all other sulphats. For 170 grains of ignited sulphat of barytes indicate 100 grains of dried sulphat of soda; while 136.36 grains of sulphat of barytes indicate 100 of dry sulphat of potass.

2. Calcareous,

2. Sulphat of lime is easily estimated by evaporating the liquid containing it to a few ounces (having previously saturated the earthy carbonats with nitric acid), and precipitating the sulphat of lime by means of weak alcohol. It may be then dried and weighed.

3. Aluminous,

3. The quantity of alum may be estimated by precipitating the alumina by carbonat of lime or of magnesia (if no lime be present in the liquid). Twelve grains

of the alumina heated to incandescence indicate 100 of crystallized alum, or 49 of the dried salt.

4. Magnesian,

4. Sulphat of magnesia may be estimated, provided no other sulphat be present, by precipitating the acid by means of a barytic salt, as 100 parts of ignited sulphat of barytes indicate 52.11 of sulphat of magnesia. If sulphat of lime, and no other sulphat accompany it, this last may be decomposed, and the lime precipitated by carbonat of magnesia. The weight of the lime thus obtained enables us to ascertain the quantity of sulphat of lime contained in the water. The whole sulphuric acid is then to be precipitated by barytes. This gives the quantity of sulphuric acid; and subtracting the portion which belongs to the sulphat of lime, there remains that which was combined with the magnesia, from which the sulphat of magnesia may be easily estimated.

If sulphat of soda be present, no earthy nitrat or muriat can exist. Therefore, if no other earthy sulphat be present, the magnesia may be precipitated by soda, dried, and weighed; 36.68 grains of which indicate 100 grains of dried sulphat of magnesia. The same process succeeds when sulphat of lime accompanies these two sulphats; only in that case the precipitate, which consists both of lime and magnesia, is to be dissolved in sulphuric acid, evaporated to dryness, and treated with twice its weight of cold water; which dissolves the sulphat of magnesia, and leaves the other salt. Let the sulphat of magnesia be evaporated to dryness, exposed to a heat of 400°, and weighed. The same process succeeds if alum be present instead of sulphat of lime. The precipitate in that case, previously dried, is to be treated with acetic acid, which dissolves the magne-

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sia, and leaves the alumina. The magnesia may be again precipitated, dried, and weighed. If sulphat of iron be present, it may be separated by exposing the water to the air for some days, and mixing with it a portion of alumina. Both the oxide of iron and the sulphat of alumina, thus formed, precipitate in the state of an insoluble powder. The sulphat of magnesia may then be estimated by the rules above explained.

5. Of iron.

5. Sulphat of iron may be estimated by precipitating the iron by means of prussic alkali, having previously determined the weight of the precipitate produced by the prussiat in a solution of a given weight of sulphat of iron in water. If muriat of iron be also present, which is a very rare case, it may be separated by evaporating the water to dryness, treating the residuum with alcohol, which dissolves the muriat, and leaves the sulphat. Or the sulphat may be estimated with great precision by the rules laid down by Mr Kirwan *.

Estimation of muriats.

V. Let us now consider the method of estimating the quantity of the different muriats which may exist in waters.

1. Alkaline,

If muriat of potass or of soda, without any other salt, exist in water, we have only to decompose them by nitrat of silver, and dry the precipitate; for 217.65 of muriat of silver indicate 100 of muriat of potass, and 235 of muriat of silver indicate 100 of common salt.

The same process is to be followed if the alkaline carbonats be present; only these carbonats must be

* *On Mineral Waters*, p. 220.

previously saturated with sulphuric acid; and we must precipitate the muriatic acid by means of sulphat of silver instead of nitrat. The presence of sulphat of soda does not injure the success of this process.

If muriat of ammonia accompany either of the fixed alkaline sulphats without the presence of any other salt, decompose the sal ammoniac by barytes water, expel the ammonia by boiling, precipitate the barytes by diluted sulphuric acid, saturate the muriatic acid with soda. The sulphat of barytes thus precipitated indicates the quantity of muriat of ammonia; 100 grains of sulphur indicating 49.09 grains of that salt. If sulphats be present in the solution, they ought to be previously separated.

2. Earthy.

If common salt be accompanied by muriat of lime, muriat of magnesia, muriat of alumina, or muriat of iron, or by all of these together without any other salts, the earths may be precipitated by barytes water, and redissolved in muriatic acid. They are then to be separated from each other by the rules formerly laid down; and their weight being determined indicates the quantity of every particular earthy muriat contained in the water. For 50 grains of lime indicate 100 of dried muriat of lime; 30 grains of magnesia indicate 100 of the muriat of that earth; and 21.8 grains of alumina indicate 100 of the muriat of alumina. The barytes is to be separated from the solution by sulphuric acid, and the muriatic acid expelled by heat, or saturated with soda; the common salt may then be ascertained by evaporation, subtracting in the last case the proportion of common salt indicated by the known quantity of muriatic acid from which the earths had been separated.

When sulphats and muriats exist together, they ought to be separated either by precipitating the sulphats by means of alcohol, or by evaporating the whole to dryness, and dissolving the earthy muriats in alcohol. The salts thus separated may be estimated by the rules already laid down.

When alkaline and earthy muriats and sulphat of lime occur together, this last salt is to be decomposed by means of muriat of barytes. The precipitate ascertains the weight of sulphat of lime contained in the water. The estimation is then to be conducted as when nothing but muriats are present; only from the muriat of lime that proportion of muriat must be deducted which is known to have been formed by the infusion of the muriat of barytes.

When muriats of soda, magnesia, and alumina, are present together with sulphats of lime and magnesia, the water to be examined ought to be divided into two equal portions. To the one portion add carbonat of magnesia till the whole of the lime and alumina be precipitated. Ascertain the quantity of lime which gives the proportion of sulphat of lime. Precipitate the sulphuric acid by muriat of barytes. This gives the quantity contained in the sulphat of magnesia and sulphat of lime; subtracting this last portion, we have the quantity of sulphat of magnesia.

From the second portion of water precipitate all the magnesia and alumina by means of lime-water. The weight of these earths enables us to ascertain the weight of muriat of magnesia and of alumina contained in the water, subtracting that part of the magnesia which existed in the state of sulphat, as indicated by the examination of the first portion of water. After this es-

timation precipitate the sulphuric acid by barytes water, and the lime by carbonic acid. The liquid evaporated to dryness leaves the common salt. Chap. IV.

VI. It now only remains to explain the method of ascertaining the proportion of the nitrats which may exist in waters. Estimation of nitrats.

1. When nitre accompanies sulphats and muriats without any other nitrat, the sulphats are to be decomposed by acetat of barytes, and the muriats by acetat of silver. The water, after filtration, is to be evaporated to dryness, and the residuum treated with alcohol, which dissolves the acetats, and leaves the nitre; the quantity of which may be easily estimated. If an alkali be present, it ought to be previously saturated with sulphuric or muriatic acid. 1. Alkaline,

2. If nitre, common salt, nitrat of lime, and muriat of lime or of magnesia, be present together, the water ought to be evaporated to dryness, and the dry mass treated with alcohol, which takes up the earthy salts. From the residuum, redissolved in water, the nitre may be separated, and estimated as in the last case. The alcohol solution is to be evaporated to dryness, and the residuum redissolved in water. Let us suppose it to contain muriat of magnesia, nitrat of lime, and muriat of lime. Precipitate the muriatic acid by nitrat of silver, which gives the proportion of muriat of magnesia and of lime. Separate the magnesia by means of carbonat of lime, and note its quantity. This gives us the quantity of muriat of magnesia. And subtracting the muriatic acid contained in that salt from the whole acid indicated by the precipitate of silver, we have the proportion of muriat of lime. Lastly, saturate the lime added to precipitate the magnesia with nitric acid. 2. Earthy.

Book II. Then precipitate the whole of the lime by sulphuric acid; and subtracting from the whole of the sulphat thus formed that portion formed by the carbonat of lime added, and by the lime contained in the muriat, the residuum gives us the lime contained in the original nitrat; and 35 grains of lime form 100 of dry nitrat of lime.

BOOK III.

OF

MINERALS.

ALL the solid materials of which this globe of ours is composed have received the name of *minerals;* and that branch of chemistry which treats of them is distinguished by the title of MINERALOGY. These substances, without doubt, must have at all times attracted the attention of mankind; because from them alone are drawn the metals, stones, and other similar substances of indispensable use. But it is only very lately that the method of ascertaining the component parts of these substances was discovered, or that it was possible to describe them so as to be intelligible to others. From the ancients no information of any consequence on these topics is to be expected. The whole science of mineralogy has been created since the year 1770, and is at present advancing towards perfection with astonishing rapidity. New minerals are every day described and analysed, collections are every where forming, and travels of discovery are succeeding each other without in-

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termission. The fruit of these labours has been the discovery of no less than five new earths and eight new metals; besides a vast number of useful minerals which had been formerly unknown or disregarded.

Mineralogy, as far as it is a chemical science, includes under it three different topics; namely, 1. An account of the properties and constituents of minerals. 2. An account of the various combinations which these bodies form; or of *compound minerals*, as they have been called. 3. The art of analysing minerals. These three topics will occupy our attention in their order. But as a technical language has been adopted by mineralogists in their descriptions, it will be necessary, in the first place, in order to render this Book intelligible, to premise a few observations on that subject.

CHAP. I.

OF THE DESCRIPTION OF MINERALS.

NOTHING at first sight appears easier than to describe a mineral, and yet in reality it is attended with a great deal of difficulty. The mineralogical descriptions of the ancients are so loose and inaccurate, that many of the minerals to which they allude cannot be ascertained; and consequently their observations, however valuable in themselves, are often, as far as respects us, altogether lost. It is obvious, that to distinguish a mineral from every other, we must either mention some peculiar property, or a collection of properties, which exist together in no other mineral. These properties must be described in terms rigidly accurate, which convey precise ideas of the very properties intended, and of no other properties. The smallest deviation from this would lead to confusion and uncertainty. Now it is impossible to describe minerals in this manner, unless there be a peculiar term for each of their properties, and unless this term be completely understood. Mineralogy therefore must have a language of its own; that is to say, it must have a *term* to denote every mineralogical property, and each of these terms must be accurately defined. The language of mineralogy was invent-

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ed by the celebrated Werner of Freyberg, and first made known to the world by the publication of his treatise on *the external characters of minerals.*

The object of this celebrated philosopher was to invent a method of describing minerals with such precision, that every species could readily be recognised by those who were acquainted with the terms employed. For this purpose, it was necessary to make use of those properties only which presented themselves to our senses on inspecting the mineral. These accordingly were chosen, and called by Werner *external characters;* because they may be ascertained without destroying the mineral examined.

Now all minerals belong to one or other of the three following heads: 1. Solid. 2. Friable, or crumbling to pieces between the fingers. 3. Fluid. There are some of the external characters which belong equally to each of these three sets of bodies; while others are confined to one or two of them. Hence Werner divides the external characters of minerals into two sets; namely, 1. Those which belong to all minerals. 2. Those which are confined to one or two of the above heads. The first of those are called *universal,* the second, *particular.*

I. Universal External Characters.

The universal external characters are eight in number; namely, 1. Colour. 2. Cohesion. 3. Lustre. 4. Feel. 5. Coldness. 6. Gravity. 7. Smell. 8. Taste.

I. Colour. With respect to the colour of minerals, five particulars require our attention. 1. The *species* of colour. 2. Its *intensity.* 3. The colour of the *sur-*

face, when it differs from the internal colour, or has any thing else remarkable. 4. The changes of colour which a mineral may have undergone. 5. The *disposition* of colours when several occur in the same mineral.

(1.) The different colours observed are referred by Werner under eight different heads; each of which is divided into a variety of shades.

1. *Whites.*

Snow white. Pure white.

Reddish white. White with a light tint of red.

Yellowish white. White with a light tint of yellow.

Silver white. Yellowish white with a metallic lustre.

Greyish-white. White with a light tint of black.

Greenish-white. White with a light tint of green.

Milk white. White with a light tint of blue.

Tin white. Milk white of a metallic lustre.

2. *Greys.*

Bluish grey. Grey with a little blue.

Lead grey. Bluish grey with a metallic lustre.

Pearl grey. Light grey with a slight mixture of violet blue.

Smoke grey. Dark grey with a little blue and brown.

Greenish grey. Light grey tinged with green.

Yellowish grey. A light grey tinged with yellow.

Steel grey. A dark grey with a light tint of yellow and a metallic lustre.

Ash grey. The darkest grey with a tint of yellow.

3. *Blacks.*

Greyish black. Black with a little white.

Brownish black. Black with a tint of brown.

Black. Pure black.

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Iron black. Pure black with a small mixture of white and a metallic lustre.

Bluish black. Black with a tint of blue.

4. Blues.

Indigo blue. A dark blackish blue.

Prussian blue. The purest blue.

Azure blue. A bright blue with scarce a tint of red.

Smalt blue. A light blue.

Violet blue. A mixture of azure blue and carmine.

Lavender blue. Violet blue mixed with grey.

Sky blue. A light blue with a slight tint of green.

5. Greens.

Verdigris green. A bright green of a bluish cast.

Seagreen. A very light green, a mixture of verdigris green and grey.

Mountain green. The preceding, but of a yellowish cast.

Emerald green. Pure green.

Grass green. Pure green with a tint of yellow.

Apple green. A light green formed of verdigris green and white.

Leek green. A very dark green with a cast of brown.

Blackish green. The darkest green, a mixture of leek green and black.

Pistachio green. Grass green, yellow and a little brown.

Olive green. A pale yellowish green with a tint of brown.

Asparagus green. The lightest green, yellowish with a little brown and grey.

6. *Yellows.*

Sulphur yellow. A light greenish yellow.

Brass yellow. The preceding, with a little less green and a metallic lustre.

Lemon yellow. Pure yellow.

Gold yellow. The preceding with a metallic lustre.

Honey yellow. A deep yellow with a little reddish brown.

Wax yellow. The preceding, but deeper.

Bronze yellow. A pale yellow with grey.

Straw yellow. A pale yellow, a mixture of sulphur yellow and reddish grey.

Wine yellow. A pale yellow with a tint of red.

Ochre yellow. Darker than the preceding, a mixture of lemon yellow with a little brown.

Isabella yellow. A pale brownish yellow, a mixture of pale orange with reddish brown.

Orange yellow. A bright reddish yellow, formed of lemon yellow and red.

7. *Reds.*

Aurora red. A bright yellow red, a mixture of scarlet and lemon yellow.

Hyacinth red. A high red like the preceding, but with a shade of brown.

Brick red. Lighter than the preceding, a mixture of aurora red and a little brown.

Scarlet red. A bright and high red, with scarce a tint of yellow.

Copper red. A light yellowish red with the metallic lustre.

Blood red. A deep red, a mixture of crimson and scarlet.

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Carmine red. Pure red verging towards a cast of blue.

Cochineal red. A deep red; a mixture of carmine with a little blue and a very little grey.

Crimson red. A deep red with a tint of blue.

Flesh red. A very pale red of the crimson kind.

Rose red. A pale red of the cochineal kind.

Peach blossom red. A very pale whitish red of the crimson kind.

Cherry red. A dark dirty crimson red; a mixture of crimson and a little brown.

Brownish red. A mixture of blood red and brown.

8. *Browns.*

Reddish brown. A deep brown inclining to red.

Clove brown. A deep brown with a tint of carmine.

Yellowish brown. A light brown verging towards ochre yellow.

Wood brown. A light brown, a mixture of yellowish brown and grey.

Hair brown. Intermediate between yellow brown and clove brown with a tint of grey.

Tombac brown. A light yellowish brown, of a metallic lustre, formed of gold yellow and reddish brown.

Liver brown. A dark brown; blackish brown with a tint of green.

Blackish brown. The darkest brown.

(2.) In respect of *intensity*, colours are either *dark*, *deep*, *light*, or *pale*. When a colour cannot be referred to any of the preceding, but is a mixture of two, this is expressed by saying, that the prevailing one *verges* towards the other, if it has only a small tint of it: *passes* into it, if it has a greater.

(3.) When the colour of the surface of a mineral

differs from its internal colour, the origin of this difference is pointed out, and the kind of colour is described. Notice is taken also whether the surface reflects the prismatic spectrum, or reflects different brilliant colours like the *opal* when its position is altered. Chap. I.

(4.) When the original colour of a mineral is changed altogether, and it has assumed another, it is then said to be altered.

(5.) When different colours appear in the same mineral, they may be disposed in *clouds*, *dots*, *streaks*, *rings*, *veins*, *zones*, &c.

II. Cohesion. With respect to cohesion, minerals are either *solid*, *friable*, or *fluid*.

III. Lustre. By this term is meant the gloss or brightness which appears on the external surface of a mineral, or on its internal surface when fresh broken. The first is called *external*, the second *internal* lustre. Two particulars respecting lustre require our attention; 1. The *degree*; 2. The *kind* of lustre. Cohesion.

(1.) With respect to degree, five terms of comparison have been chosen; namely, 1. Very brilliant; 2. Brilliant; 3. Sub-brilliant; 4. Glimmering, that is, having only certain parts brilliant; 5 Dull, or without lustre*.

(2.) With respect to *kind*, the lustre is either, 1, *Metallic*; or, 2. *Common*. The common lustre is subdivided into *vitreous* or *glossy*, *silky*, *waxy* or *greasy*, *mother of pearl*, *diamond*, and *semimetallic*.

IV. Feel. By the feel of minerals is meant the sensation which their surfaces communicate when han- Fe

* These four degrees have been denoted by Mr Kirwan by the figures 4, 3, 2, 1, and no lustre by 0.

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dled. Minerals, with respect to feel, are either *dry*, *somewhat greasy*, *greasy*, or *very greasy*.

V. Coldness.
VI. Specific gravity.
VII. Smell.
VIII. Taste.

} These characters require no particular description.

II. Particular External Characters.

The particular external characters are subdivided, of course, into three heads: 1. The first including those that belong to solid minerals; the second, to friable; and the third, to fluid.

1. *Particular Characters of solid Minerals.*—The particular characters of solid minerals are 14 in number; namely,

1. Form or figure,
2. Surface,
3. Fracture or texture,
4. Structure,
5. Fragments,
6. Transparence,
7. Scratch,
8. Stain,
9. Hardness,
10. Ductility,
11. Tenacity,
12. Flexibility,
13. Adherence to the tongue,
14. Sound.

Form.

I. Form. The form of minerals is either, 1. Common; 2. Imitative; or, 3. Regular.

(1.) *Common.* The form is said to be *common*, when it is too irregular to be compared to the form of any other body. In that case a mineral is often called *amorphous*.

(2.) *Imitative* or *particular*. The form is said to be imitative when it can be referred to some known body. The imitative forms are: *Globular*, like a globe; *oval*, like an oblong spheroid; *ovate*, like an egg; *cheese-shaped*, a very flattened sphere; *almond-shaped*,

like an almond; *lenticular*, like a double convex lens, compressed and gradually thinner towards the edges; *cuneiform*, like a wedge; *nodulous*, having depressions and protuberances like a potatoe; *botryoidal*, like grapes closely pressed together; *dentiform*, longish and tortuous, and thicker at the bottom than the top; *wireform*, like a wire; *capillary*, like hair, finer than the preceding; *retiform*, threads interwoven like a net; *dendritic*, like a tree, having branches issuing from a common stem; *shrubform*, branches not arising from a common stem; *coraloidal*, branched like coral; *stalactitical*, like icicles; *clavated*, like a club, long, and thicker at one end than another; *fasciform*, long straight cylindrical bodies, united like a bundle of rods; *tubular*, cylindrical and hollow.

(3.) *Regular*. The form of minerals is said to be regular when they are crystallized.

II. By SURFACE is meant the appearance of the external surface of minerals. The *surface* is either *uneven*, composed of small unequal elevations and depressions; *scabrous*, having very small *sharp* and rough elevations, more easily felt than seen; *drusy*, covered with very minute crystals; *rough*, composed of very minute *blunt* elevations, easily distinguishable by the feel; *scaly*, composed of very minute thin scale-like leaves; *smooth*, free from all inequality or roughness; *specular*, having a smooth polished surface like a mirror; or *streaked*, having elevated, straight, and parallel lines. This last character is confined to the *surface* of crystals. The *streaks* are either *transverse*; *longitudinal*; *alternate*, in different directions on different faces; *plumose*, running from a middle rib; or *decussated*, crossing each other.

Surface.

III. FRACTURE or TEXTURE. By this is meant

Fracture or texture.

the appearance which the internal surface of a mineral presents when broken, provided it be not fractured in the direction of one of the natural points of the mineral. This appearance obviously depends upon the texture of the mineral; hence this character is sometimes called *fracture*, sometimes *texture*. The fracture is either, 1. Compact. 2. Fibrous. 3. Radiated. 4. Lameller or foliated.

(1). *Compact.* The fracture is called compact when all the parts of the internal surface are continuous. The small inequalities which occur in this fracture are thus distinguished. 1. *Scaly*, when small inequalities cover one another and come off in scales. 2. *Even*, destitute of perceptible inequalities. 3. *Conchoidal*, small hollows like the print of shells. 4. *Uneven*, having many small, sharp, abrupt, irregular elevations and inequalities; and from the size of these, this fracture is denominated *coarse*, *small*, or *fine*. 5. *Earthy*, when the internal surface resembles dried earth. 6. *Rugged* or *hackly*, having many very minute sharp hooks, more sensible to the hand than the eye. This last fracture is peculiar to the metals.

(2.) *Fibrous.* The fracture is called fibrous, when the internal surface shows the mineral composed of fibres or threads adhering together, and too small to be measured. These fibres are either *straight* or *curved*, and they are disposed either in *parallels*, or they *diverge* from each other, or they are *interwoven* together.

(3.) *Radiated.* The fracture is called radiated when the fibres are flattish and so large that their breadth admits of measurement. The internal surface in that case exhibits *striæ* or *channels*.

(4.) *Foliated.* The fracture is called *foliated* when

the mineral appears composed of thin plates whose surfaces are smooth and polished like the surface of a crystal. The plates may be either *large*, *small* or *very small*; *perfect*, *imperfect* or *doubtful*; *straight* or *curved* in various ways. The direction of the plates, or the *clivage*, may be either simple, double, or triple.

Structure.

IV. The STRUCTURE or COMPOUND TEXTURE is the manner in which the parts that form the texture are disposed. It is either *slaty*, in straight layers like slate; *testaceous*, in incurvated layers; *concentric*, inconcentric layers; or *columnar*, in columns.

The *texture* and *structure* may at first view appear the same; but in reality they are very different. Thus common slate has often the *slaty structure* and *earthy texture*. The texture of pitcoal is compact, but its structure is often slaty.

Fragments.

V. By FRAGMENTS is meant the shape of the pieces into which a mineral breaks when struck with a hammer. They are either 1. *regular*, or, 2. *irregular*.

(1.) By *regular* fragments are meant those which have a geometrical form. They are usually the fragments of crystallized bodies; and are either *cubic*, *rhomboidal*, *trapezoidal*, *tetrahedral*, *octahedral*, or *dodecahedral*.

(2.) By *irregular* are meant the fragments which have not a geometrical form; they are *wedge-shaped*; *splintery*, thin, long and pointed; *tabular*, thin, and broad, and sharp at the corners, as common slate; or *indeterminate*, without any particular resemblance to any other body. The *edges* of indeterminate fragments are either *very sharp*, *sharp*, *sharpish*, or *blunt*.

Transparency.

VI. By TRANSPARENCY is meant the proportion of light which minerals are capable of transmitting. They

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are *transparent* or *pellucid* when objects can be seen distinctly through them; *diaphanous*, when objects are seen through them indistinctly; *subdiaphanous*, when light passes but in so small a quantity that objects cannot be seen through them *; *opaque*, when no light is transmitted.

When opaque minerals become transparent in water, they are called *hydrophanous*. When objects are seen double through a transparent mineral, it is said to *refract doubly*.

Scratch.

VII. By the SCRATCH or STREAK, is meant the mark left when a mineral is scratched by any hard body, as the point of a knife. It is either *similar*, of the same colour with the mineral; or *dissimilar*, of a different colour.

Stain.

VIII. By STAIN, is meant the trace which some minerals leave when rubbed upon paper. Some minerals leave a *stain* or trace, others not. Some of the first kind may be employed to write with, others not.

Hardness.

IX. By HARDNESS, is meant the resistance which a body opposes when we attempt to scratch it. Minerals are either, 1. hard, 2. hardish, 3. soft, 4. very soft.

(1.) Minerals are called *hard* when they do not yield to the knife, and strike fire with steel. There are three degrees of it. 1. Extremely hard, not yielding to the file. 2. Very hard, yielding a little to the file. 3. Hard, yielding to the file.

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* According to Mr Kirwan's method, I have denoted these three degrees of transparency by the figures 4, 3, 2. When a mineral is subdiaphanous only at the edge, that is denoted by the figure 1. Opacity is sometimes denoted by 0.

(2.) Minerals are hardish when they yield with difficulty to the knife, and do not strike fire with steel.

(3.) *Soft*, when they yield easily to the knife, but not to the nail.

(4.) *Very soft*, when they yield to the nail.

I have used Mr Kirwan's figures to denote the comparative HARDNESS of bodies; for an explanation of which the reader is referred to Vol. I. p. 106. of this Work.

Ductility.

X. With respect to DUCTILITY, minerals are either,

(1.) *Brittle*, incapable of being hammered.

(2.) *Sectile*, capable of being cut, but not hammered.

(3.) *Ductile*, capable of being hammered.

Tenacity.

XI. By TENACITY, is meant the resistance which minerals oppose to the stroke of a hammer when we attempt to break them. In this respect they are, 1. *extremly tough*. 2. *Very tough*. 3. *Tough*. 4. *Fragile*. 5. *Very fragile*.

Flexibility.

XII. By FLEXIBILITY, is meant the property of bending without breaking. Some minerals are (1.) *Flexible*, and of these some are, 1. Elastic; others, 2. Not elastic. (2.) Others *inflexible*.

Adherence.

XIII. ADHERENCE TO THE TONGUE. Some minerals adhere, 1. Very *strongly*, 2. others *moderately*, 3. others *slightly*, 4. and others very *slightly*.

Sound.

XIV. By SOUND, is meant the peculiar noise emitted by some minerals when struck or bent. Some give a *clear* sound, as *slate*; others a *dull* sound; some *creak* when bent, as tin.

Friable minerals.

2. *Particular characters of friable minerals.*—These are seven in number; most of which have been already discribed in the particular characters of solid minerals.

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I. EXTERNAL FIGURE. The external figure of friable minerals is always common.

II. APPEARANCE. By this is meant the figure of the small parts of which the friable minerals are composed. These parts are either, 1. *Pulverulent*, 2. *Scales*, 3. *Sand*.

III. STAIN. All friable minerals leave a trace when rubbed upon paper.

IV. FRIABLENESS. By this is meant the degrees of adhesion between the parts of friable minerals. They are either *coherent* or in *powder*.

V. VI. VII. The ADHERENCE to the tongue, the SCRATCH, and the SOUND, are the same as in solid minerals.

Fluid minerals.

3. *Particular characters of fluid minerals.*—These are only two in number; namely.

I. TRANSPARENCE. They are either, 1. DIAPHANOUS or *pellucid*, 2. muddy, 3. opake.

II. FLUIDITY. They are either *perfectly fluid* or *viscid*.

With respect to ELECTRICITY, some minerals become electric when *heated*, others when *rubbed*, others cannot be rendered electric. The electricity of some minerals is *positive* or *vitreous*, of others *negative* or *resinous*.

Blow-pipe.

The CHEMICAL properties of minerals will be understood without any explanation. In detecting them, the *blow-pipe* is often of singular use, as it enables us in a few minutes to determine many points which by the usual processes would occupy a great deal of time. The blow-pipe is merely a tube ending in a cavity as fine as a small wire, through which air is forced and made to play upon the flame of a candle, by means of

which the flame is concentrated and directed against small particles of the mineral to be examined, either placed upon a bit of charcoal or in a platinum or silver spoon. The air is either forced into the blow-pipe by the lungs of the experimenter, or by means of bellows attached to the blow pipe. By thus exposing a very small portion of a mineral to the concentrated flame, we see the effect of heat upon it, and have an opportunity of trying the action of other bodies on it at a very high temperature, as of borax, soda, microcosmic salt, &c. The properties which these experiments bring into view, enable us in many cases to ascertain the nature, and even the component parts, of a mineral.

The blow-pipe was first introduced into mineralogy by Von Swab. It was afterwards improved by Cronstedt, and still farther by Bergman. Saussure substituted a fine splinter of cyanite for charcoal, cemented a very minute portion of the mineral to be examined to the point of this splinter, and exposed it in that situation to the action of the blow-pipe. By this contrivance he was enabled to make his experiments upon very minute particles; and this enabled him to fuse many bodies formerly considered as infusible.

CHAP. II.

OF SIMPLE MINERALS.

Avicenna, a writer of the 11th century, divided minerals into four classes; stones, salts, inflammable bodies, and metals *. This division has been, in some measure, followed by all succeeding writers. Linnæus, indeed, the first of the moderns who published a system of mineralogy, being guided by the external characters alone, divided minerals into three classes, *petræ*, *mineræ*, *fossilia*: but Avicenna's classes appear among his orders. The same remark may be made with respect to the systems of Wallerius, Wolsterdorf, Cartheuser, and Justi, which appeared in succession after the first publication of Linnæus's *Systema Naturæ*, in 1736. At last, in 1758, the system of Cronstedt appeared. He reinstated the classes of Avicenna in their place; and his system was adopted by Bergman, Kirwan, Werner, and the most celebrated mineralogists

* Corpora mineralia in quatuor species dividuntur, scilicet in lapides, et in liquefactiva, sulphurea, et sales. Et horum quædam sunt raræ substantiæ et debilis compositionis, et quædam fortis substantiæ, et quædam ductibilia, et quædam non. Avicenna *de Congelatione et Conglutinatione Lapidum*, chap. iii. *Theatrum Chemicum*, t. iv. p. 997.

who have written since. These classes shall be adopted in the present Work, because none which are preferable have been hitherto proposed.

Division.

I shall therefore divide minerals into four Classes:

1. Stones;
2. Salts;
3. Combustibles;
4. Ores.

The first Class comprehends all the minerals which are composed chiefly of earths; the second, all the combinations of acids and alkalies which occur in the mineral kingdom; the third, those minerals which are capable of combustion, and which consist chiefly of sulphur, carbon, and oil; the fourth, the mineral bodies which are composed chiefly of metals.

CLASS I.

STONES.

THIS class naturally divides itself into two orders. The first order comprehends under it all the combinations composed entirely of earthy bodies, or of earthy bodies united with only a small portion of an alkali or metallic oxide: The second order consists of combinations of earthy bodies with acids. To the first order, for want of a better term, we shall give the appellation *earthy stones*; to the second, that of *saline stones*.

ORDER I. EARTHY STONES.

CRONSTEDT divided this order into nine genera, corresponding to nine earths; one of which he thought composed the stones arranged under each genus. The names of his genera were, *calcareæ*, *siliceæ*, *granatinæ*, *argillaceæ*, *micaceæ*, *fluores*, *asbestinæ*, *zeolithicæ*, *magnesiæ*. All his earths were afterwards found to be compounds, except the first, second, fourth, and ninth. Bergman, therefore, in his *Sciagraphia*, first published in 1782, reduced the number of genera to five; which was the number of primitive earths known when he wrote. Since that period five new earths have been

discovered. Accordingly, in the latest systems of mineralogy, the genera belonging to this order are proportionally increased. Each genus is named from an earth; and they are arranged in the newest Wernerian system, which I have seen, as follows: Class I. Order I.

1. Jargon genus,
2. Siliceous genus,
3. Glucina genus,
4. Argillaceous genus,
5. Magnesian genus,
6. Calcareous genus,
7. Barytic genus,
8. Strontian genus.

Mr Kirwan, in his very valuable system of mineralogy, has adopted the same genera. Under each genus, those stones are placed which are composed chiefly of the earth which gives a name to the genus, or which at least are supposed to possess the characters which distinguish that earth.

A little consideration will be sufficient to discover that there is no natural foundation for these genera. Most stones are composed of two, three, or even four ingredients; and, in many cases, the proportion of two or more of these is nearly equal. Now, under what genus soever such minerals are arranged, the earth which gives it a name must form the smallest part of their composition. Accordingly, it has not been so much the chemical composition, as the external character, which has guided the mineralogist in the distribution of his species. The genera cannot be said properly to have any character at all, nor the species to be connected by any thing else than an arbitrary title. This defect, which must be apparent in the most valuable systems of mineralogy, seems to have arisen chiefly from an attempt to combine together an artificial

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and natural system. As my object at present is to give a view of these bodies according to their composition, it will be necessary to follow a different plan.

Substances found in stony bodies.

The only substances which enter into the minerals belonging to this order, in such quantity as to deserve attention, are the following:

Alumina, A	Oxide of iron, I
Silica, S	Oxide of chromium, C
Magnesia, M	Oxideof nickel, N
Lime, L	Oxide of copper, K
Barytes, B	Potass, P
Glucina, G	Soda, O
Zirconia, Z	Water, W
Yttria, Y	

Arrangement.

All those minerals which are composed of the *same* ingredients I arrange under the *same* genus. According to this plan, there must be as many genera as there are varieties of combinations of the above substances existing in nature. The varieties in the *proportion* of the ingredients constitute species. I have not imposed names upon these genera; but, in imitation of Bergman *, have denoted each by a symbol. This symbol is composed of the first letter of every substance which enters in any considerable quantity into the composition of the minerals arranged under the genus denoted by it †. Thus, suppose the minerals of a genus to be composed of *alumina*, *silica*, and *oxide of iron*, I denote

* *Opusc.* iv. 231.

† For distinction's sake, Copper is denoted by the letter K; and Soda by its second letter O.

Class I. Order I.

the genus by the symbol Asi. The letters are arranged according to the proportion of the ingredients; that which enters in the greatest proportion being put first, and the others in their order. Thus the genus Asi is composed of a considerable proportion of alumina, of a smaller proportion of silica, and contains least of all of iron. By this contrivance, the symbol of a genus contains, within the compass of a few letters, a pretty accurate description of its nature and character. Where the proportions of the ingredients vary in the same genus so much, that the letters which constitute its symbol change their place, I subdivide the genus into parts; and whenever the properties of minerals vary in a striking manner, according to this proportion, each of these parts is made a distinct genus.

The following is a view of the different genera belonging to this order, denoted each by its symbol. Every genus is followed by the species included under it; and the whole are in the order which I mean to follow in describing them.

Table of genera and species.

I. A.
- 1. Diaspore
- 2. Native alumina

II. As.
- 1. Corundum—Emery
- 2. Chrysoberyl
- 3. Topaz
- 4. Fibrolite
- 5. Sommite

III. Am.
- 1. Spinell
- 2. Geylanite

IV. S.
- 1. Quartz
- 2. Chrysoprase
- 3. Flint
- 4. Opal—Cat's eye

V. Zs.
- 1. Zircon

VI. Sa.
- 1. Shorlite
- 2. Hornstone
- 3. Pitchstone

4. Chalcedony
5. Plasma
6. Heliotrope
7. Jasper
8. Tripoli
9. Porcelain earth
10. Clay
11. Cimolite
12. Poliershiefer
13. Black chalk
14. Fullers earth

VII. Sai.
1. Mica
2. Talc
3. Hornblende
4. Obsidian

VIII. Asi.
1. Shorl—Suberite
2. Pinite
3. Granatite

IX. Snaw.
1. Pimelite

X. Sap.
1. Lepidolite
2. Leucite
3. Felspar
4. White chlorite

XI. Sag.
1. Emerald
2. Euclose

XII. Sab.
1. Staurolite

XIII. Sla.
1. Lazulite

XIV. Sal.
1. Scapolite
2. Dipyre
3. Hyalite

2. sawl.
4. Zeolite
5. Stilbite
6. Analcime
7. Chabasie
8. Prehnite

XV. Sali.
1. Thummerstone—Kaupholite
2. Thallite
3. Scorza
4. Garnet—Aplome
5. Pyrope

XVI. Sail.
1. Basalt
2. Wacken
3. Klingstein
4. Keiselshiefer
5. Green earth

XVII. Ams.
1. Cyanite

XVIII. Msa.
1. Serpentine
2. Nephrite

XIX. Msai.
1. Potstone
2. Chlorite
3. Lithomarga

XX. Saim.
1. Melanite
XXI. Samli.
1. Slate
2. Bole
XXII. Slacmi.
1. Smaragdite
XXIII. Sm.
1. Kiffekill
2. Steatites
XXIV. Msi.
1. Chrysolite
XXV. Sml.
1. Asbestus
2. Actinote
3. Malacolite
XXVI. Silm.
1. Augite
XXVII. Smil.
1. Vesuvian
2. Meionite
XXVIII. Sl.
1. Tremolite
XXIX. Slk.
1. Dioplase
XXX. Ysi.
1. Gadolinite

The minerals belonging to this order possess the following common properties: A specific gravity varying from 4.4 to 0.7. The greater number of them are hard enough to scratch glass; and this is always the case when the specific gravity exceeds 3.5. Some of them, however, are as soft as cotton. None of them have the true metallic lustre; though some possess the false metallic lustre, which disappears on scratching them. None of them are soluble in water; and very few of them are soluble in acids without some peculiar mode of applying them. Hitherto it has been impossible for chemists to form any of them by art.

Genus I. A.

This genus contains no minerals which occur in well-defined crystals. The sapphire was formerly considered as pure alumina crystallized; but the late ana-

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lyses of Chenevix have uniformly detected a small portion of silica.

Sp. 1. Diaspore*.

Properties. This mineral was first noticed by Lelievre, and described by Hauy. Nothing is known concerning the part of France where it was found. Its colour is grey. It occurs in masses composed of plates slightly curved, and easily separable from each other. Lustre considerable, pearly. Divisible into plates in another direction, forming with the first an angle of 130°. Scratches glass. Before the flame of a candle decrepitates, and disperses in small pieces†. Specific gravity 3.4324.

Composition. According to the analysis of Vauquelin, it is composed of . . . . . 80 alumina

17 water

3 oxide of iron

100

Sp. 2. Native Alumina‡.

This substance has been found at Halles in Saxony in compact kidney-form masses. Its consistence is earthy.

Properties. Lustre 0. Opaque. Hardness 4. Brittle. Specific gravity 1.305 to 1.669. Feels soft, but meagre. Adheres very slightly to the tongue. Stains very slightly. Colour snow white, or yellowish white. Does not readily diffuse itself in water.

It consists, according to Schreber, of pure alumina

* Hauy's *Mineralogie*, iv. 358.—Brochant's *Mineralogie*, ii. 507.—Vauquelin, *Ann. de Chim.* xlii. 113.

† Hence the name given it by Hauy.

‡ See Kirwan's *Min.* i. 175.—and Schreber, 15 Stuck, p. 209.—Brochant, i. 318.

mixed with a small quantity of carbonat of lime, and sometimes of sulphat of lime; but Fourcroy has lately announced the result of his analysis as follows: Class I. Order I.

Composition.

45 alumina
24 sulphat of lime
27 water
4 lime, silica, and muriat of lime

100*

Genus II. As.

The minerals belonging to this genus are composed of alumina combined with a small portion of silica. They differ from those of the last in containing little or no water; in being almost always crystallized, and excessively hard. This hardness, together with their beauty, has given most of them a place among precious stones. History.

Sp. 1. Corundum.

The late experiments of Chenevix, and the observations of Bournon, have made it necessary to comprehend under this species several minerals formerly considered separately under the names of sapphire, corundum, and adamantine spar. The analysis of Smithson Tennant has shewn that *emery* also belongs to the same species.

The stones usually called precious were first distinguished on account of their colour. Those that had a red colour were called *rubies*; the yellow were *topa-*

* *Jour. de Chim.* iv. 125.

zes; the blue, *sapphires*; and the purple, *amethysts*. It was soon observed, however, that most of the properties for which these stones were valued were proportional to their hardness; and as the finest kind came from the East, it was usual with lapidaries to distinguish them by the epithet *oriental*. Mineralogists were accustomed to consider these stones as distinct species, till Romé de Lisle observed that they agreed in the form of their crystals, their hardness, and most of their other properties; and Werner made the same remark about the same time. These observations were sufficient to constitute them one species; and accordingly they were made one species by Romé de Lisle himself, by Kirwan, and several other modern mineralogical writers. Romé de Lisle gave the species the name of *ruby*; but this has been since confined to a different mineral. This induced Hauy to invent the new word *telesia*; but the term *sapphire*, appropriated to this species by Werner and Delametherie, was adopted by mineralogists in general.

Mineralogists had agreed in reducing these different varieties of precious stones under the same species before they became acquainted with the mineral called *corundum*. This stone, though it appears to have been known to Mr Woodward, may be said to have been first distinguished from other minerals by Dr Black. In 1768, Mr Berry, a lapidary in Edinburgh, received a box of it from Dr Anderson of Madras. Dr Black ascertained that these specimens differed from all the stones known to Europeans; and, in consequence of its hardness, it obtained the name of *adamantine spar*. Notwithstanding this, it could scarcely be said to have been known to European mineralogists till Mr Greville

Class I. Order I.

of London, who has done so much to promote the science of mineralogy, obtained specimens of it, in 1784, from India, and distributed them among the most eminent chemists, in order to be analysed. Mr Greville also learned that its Indian name was Corundum. It is found in Indostan, not far from the river Cavery, which is south from Madras, in a rocky matrix, of considerable hardness, partaking of the nature of the stone itself*. It occurs also in China, and in Ceylon, Ava, &c. The Count de Bournon pointed out the resemblance between this mineral and the sapphire in a dissertation published by him and Mr Greville in the Philosophical Transactions for 1798, and suggested it as probable that corundum may be only a variety of the sapphire; and that the seeming difference in their ingredients is owing to the impurity of those specimens of corundum which have hitherto been brought to Europe. This conjecture has been since demonstrated by a subsequent dissertation of Bournon, and the chemical analysis of Chenevix†. This species, then, must be divided into two *subspecies*: the first, the *perfect corundum* or *sapphire* of mineralogists; the second, the *imperfect corundum* or *corundum* of mineralogists. To this the analysis of Mr Smithson Tennant warrants us to add a third, namely, *emery*.

Subspecies 1. Perfect Corundum ‡.

Oriental ruby, *sapphire*, and *topaz*—*Rubis d'orient* of

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* Garrow and Greville, Nicholson's *Jour.* ii. 540.

† *Phil. Trans.* 1802, p. 233.

‡ See Kirwan's *Mineralogy*, i. 250.—Gmelin's *Systema Naturæ* of Linnæus, iii. 170.—Romé de Lisle's *Crystallographie*, ii. 212.—Bergman's *Opusc.* ii. 72.—Brochant, i. 207.—Hauy, ii. 480.

Romé de Liſle—*Telasia* of Hauy—*Sapphire* of Delametherie.

Perfect corundum or sapphire is found in the East Indies, especially in Pegu and the island of Ceylon; and it is most commonly crystallized. The crystals are of no great size: Their primitive form, as has been demonstrated by Bournon, is a rhomboid, whose angles are 86° and 94°, and which therefore is nearly rectangular. Sometimes it occurs in this form, though but seldom. Bournon has described no less than eight modifications of it. We may consider the primitive form as composed of two trihedral pyramids united base to base, the solid angles of which are composed of three acute angles of the faces. The eight modifications are, 1. The summit of the pyramids is replaced by a face perpendicular to the axis, and of various sizes. 2. The edges of the base of the primitive pyramids are replaced by faces parallel to the axis, which separates the pyramids by a six-sided prism, with rhombic planes. Often this modification runs into a regular six-sided prism. 3. A decrement takes place on the flat angles of the base, which converts the pyramids to six-sided, so that the crystal is often a dodecahedron, composed of two ſix-sided pyramids applied base to base; but it is very seldom that both pyramids are complete. This modification is often combined with the second. 4. The solid angle at the summit is replaced by three faces, which sometimes become so large as to cause the faces of the primative rhomboid to disappear, and converts the crystal into a secondary rhomboid, whose faces have angles of 114° and 66°. 5. A more rapid decrement of the same kind produces a rhomboid still more acute, the faces of which have angles of 117° and 63°. 6. Similar decrements, still more rapid, form a third rhomboid

Crystals.

still more acute, whose faces have angles of 119° 14 and 60° 46′. 7. The acute angles which rest upon the base of the primitive pyramids suffer a decrement, which converts the crystal into a six-sided prism, whose faces correspond with the solid angles of the base of the primitive pyramids. 8. A six-sided pyramid, the solid angle of whose summit measures 24°. Each of the edges of the pyramid is replaced by a small face, which makes the pyramid a dodecahedron *.

The texture of the sapphire is foliated; but in the more perfect specimens the plates are separated with difficulty. Fracture conchoidal. Its lustre varies from 3 to 4. Vitreous. Transparency usually 3 or 4, sometimes only 2. It causes only a single refraction. Specific gravity from 3.907 to 4.161. Hardness from 15 to 17. Colour most frequently blue, sometimes red, purple, yellow, and green, and sometimes colourless. Properties.

Subspecies 2. Imperfect Corundum †.

Corundum of Gmelin—*Adamantine spar* of Klaproth and Kirwan—*Corindon* of Hauy—*Corivindum* of Woodward.

Usually crystallized; sometimes found in amorphous masses. The figures of the crystals are the same as those of the last subspecies. Lustre, when in the direction of the laminæ, 3; when broken across, 0. Opaque, except when in very thin pieces. Hardness 15. Spe- Properties.

* *Phil. Trans.* 1802. p. 250.

† See Kirwan's *Min.* i.—Klaproth *in Beob. der Berlin*, viii. 295. and Beitrage, i. 47.—Mr Greville and the Count de Bournon in the *Philosophical Transactions* 1798, p. 403, and in Nicholson's *Jour.* ii. 540. and iii. 5.—Mr Hauy, *Jour. de Phys.* xxx. 193. and *Jour. de Min.* No. xxviii. 262, and Mineral 3. 1.—Brochant, i. 356.

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cific gravity from 3.710 to 4.180 *. Colour grey, often with various shades of blue and green.

Mr Chenevix obtained the following constituents from different specimens of corundum subjected to chemical analysis.

IMPERFECT CORUNDUM.

Composition.

	From the Carnatic.	From Malabar	From China.	From Ava.
Silica . . .	5.0	7.0	5.25	6.5
Alumina .	91.0	86.5	86.50	87.0
Iron . . .	1.5	4.0	6.50	4.5
Loss . . .	2.5	2.5	1.75	2.0
	100.0	100.0	100.00	100.0

PERFECT CORUNDUM.

	Blue, or sapphire.	Red, or oriental ruby.
Silica	5.25	7.0
Alumina	92.00	90.0
Iron	1.00	1.2
Loss	1.75	1.8
	100.00	100.0

Mr Klaproth's analysis of sapphire differs a little from the above; but his analysis of imperfect corundum agrees with it. He found the sapphire composed of

98.5 alumina
1.0 oxide of iron
0.5 lime

100.0 †

* Klaproth. See also Greville, Nicholson's *Jour.* iii. 11.
† Beitrage, i. 81.

Class I. Order I.

The corundum from

India.	China.
89.50	84.0 alumina
5.50	6.5 silica
1.25	7.5 iron
96.25	98.0

Subspecies 3. Emery.

Properties.

This mineral is brought to Britain from the isle of Naxos, where it must exist in great abundance. It occurs also in Germany, Italy, and Spain. It is always in shapeless masses, and mixed with other minerals. It has been usually considered as an iron ore, because it is always contaminated with the oxide of that metal. Its colour is blackish or bluishgrey. Its lustre is inconsiderable. Usually opaque. Very hard. Brittle. Specific gravity about 4.

Composition.

From the analysis of Smithson Tennant, it follows that emery, freed as much as possible from iron, is composed of

80 alumina
3 silica
4 iron

87 *

This analysis corresponds very nearly with that of the imperfect corundum. The use of emery in grinding and polishing hard bodies is sufficiently known.

* *Phil. Trans.* 1802. p. 400.

Sp. 2. Chrysoberyl*.

Oriental chrysolite of jewellers—*Cymophane* of Hauy—*Chrysopal* of Delametherie.

Hitherto this stone has been found only in Brazil, the island of Ceylon, and as some affirm near Nortschink in Siberia. Werner first made it a distinct species, and gave it the name which it now bears. It is usually found in round masses about the size of a pea, but it is sometimes also crystallized. The primitive form of its crystals is a four-sided rectangular prism, whose height is to its breadth as $\sqrt{3}$ to 1, and to its thickness as $\sqrt{2}$ to 1. The most common variety hitherto observed is an eight-sided prism, terminated by six-sided summits. Two of the faces of the prism are hexagons, two are rectangles, and four trapeziums; two faces of the summits are rectangles, and the other four trapeziums. Sometimes two of the edges of the prism are wanting, and small faces in their place †.

Crystals.

Its texture is foliated. Laminæ parallel to the faces of the prism. Lustre 3 to 4. Transparency 3 to 4. Causes double refraction. Hardness 12. Specific gravity from 3.698‡ to 3.7961§. Colour yellowish green, surface sparkling. It is infusible by the blow-pipe *per se*, and with soda.

Properties.

A specimen of chrysoberyl, analysed by Klaproth, was composed of

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* Kirwan, i. 262.—Brochant, i. 167.—Hauy, ii. 491.

† Hauy, *Jour. de Min.* No. xxi. 5.

‡ Werner. § Hauy.

71.5 alumina
18.0 silica
6.0 lime
1.5 oxide of iron

97.0 *

Class I. Order I. Composition.

Sp. 3. Topaz †.

Occidental ruby, *topaz*, and *sapphire*.

History. The name *topaz* has been restricted by Mr Hauy to the stones called by mineralogists occidental ruby, topaz, and sapphire; which, agreeing in their crystallization and most of their properties, were arranged under one species by Mr Romé de Lisle. The word *topaz*, derived from an island in the Red Sea ‡, where the ancients used to find topazes, was applied by them to a mineral very different from ours. One variety of our topaz they denominated *chrysolite*.

The topaz is found in Saxony, Bohemia, Siberia, and Brazil, mixed with other minerals in granite rocks.

Crystals. It is commonly crystallized. The primitive form of its crystals is a prism whose sides are rectangles and bases rhombs, having their greatest angles 124° 22′, and the integral molecule has the same form §; and the height of the prism is to a side of the rhomboidal bases

* Beitrage, i. 102.

† Kirwan's *Min.* i. 254.—Pott, *Mem. Berlin*, 1747, p. 46.—Margraf, ibid. 1776, p. 73, and 160.—Henkel, *Act. Acad. Nat. Cur.* iv. 316.—Bi-chant, i. 212.

‡ It got its name from τοπαζω, *to seek*; because the island was often surrounded with fog, and therefore difficult to find. See Plinii, lib. xxxvii. c. 8.

§ Hauy, *Jour. de Min.* No. xxviii. 287.

as 3 to 2. The different varieties of topaz crystals hitherto observed amount to 6. Five of these are eight-sided prisms, terminated by four-sided pyramids, or wedge-shaped summits, or by irregular figures of 7, 13, or 15 sides; the last variety is a twelve-sided prism, terminated by six-sided pyramids wanting the apex. For an accurate description and figure of these varieties the reader is referred to Mr Hauy *.

Properties. The texture of the topaz is foliated. Its lustre is from 2 to 4. Transparency from 2 to 4. It causes a double refraction. Hardness 12 to 14. Specific gravity from 3.464 to 3.564. The Siberian and Brazil topazes, when heated, become positively electrified on one side, and negatively on the other †. It is infusible by the blow-pipe. The yellow topaz of Brazil becomes red when exposed to a strong heat in a crucible; that of Saxony becomes white by the same process. This shews us that the colouring matter of these two stones is different.

The colour of the topaz is various; which has induced mineralogists to divide it into the following varieties:

Varieties. 1. Red topaz, of a red colour, inclining to yellow; called *Brazilian* or *occidental ruby*.

2. Yellow topaz, of a golden yellow colour, and sometimes also nearly white; called *occidental* or *Brazil topaz*. The powder of this and the following variety causes syrup of violets to assume a green colour ‡.

3. Saxon topaz. It is of a pale wine yellow colour, and sometimes greyish white.

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* Hauy, *Jour. de Min.* No. xxviii. 287. † Hauy, Ibid.

‡ Vauquelin, Ibid. No. xxix. 165.

4. Aigue marine. It is of a bluish or pale green colour. Class I. Genus II. As.

5. Occidental sapphire. It is of a blue colour; and sometimes white.

A specimen of white Saxon topaz, analysed by Vauquelin, contained

68 alumina
31 silica

99*

Sp. 3. Fibrolite†.

This mineral was first observed by Bournon in the matrix of the imperfect corundum. Colour white or dirty grey. Hardness rather greater than that of quartz. Specific gravity 3.214. Texture fibrous. Cross fracture compact. Internal lustre glossy. Infusible by the blow-pipe. Usually in shapeless fragments. Bournon observed one specimen crystallized in a rhomboidal prism; the angles of whose faces were 80° and 100°. It is composed, according to Chenevix, of Properties.

58.25 alumina
38.00 silica
3.75 a trace of iron and loss

100.00‡ Composition.

Sp. 4. Sommite§.

Nepheline of Hauy—*Hexagonal white shorl* of Ferber—*White hyacinth* of Somma.

This stone was called *sommite* by Lametherie, from

* Vauquelin, *Jour. de Min.* No. xxiv. 3.
† Bournon, *Phil. Trans.* 1802, p. 289. ‡ Ibid. p. 335.
§ Brochant, ii. 522.—Hauy, iii. 186.

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the mountain Somma, where it was first found. It is usually mixed with volcanic productions. It crystallizes in six-sided prisms, sometimes terminated by pyramids. Colour white. Somewhat transparent. Cuts glass. Specific gravity 3 2741. Infusible by the blowpipe. Acccording to the analysis of Vauquelin, it is composed of

49	alumina
46	silica
2	lime
1	oxide of iron
98*	

Genus III. Am.

Sp. 1. Spinell†.

Spinel and *balass ruby* of Kirwan—*Rubis spinelle octoedre* of De Lisle—*Spinellus* of Gmelin.

This stone, which comes from the island of Ceylon, is usually crystallized. The form of its integrant particles is the tetrahedron. The primitive form of its crystals is a regular octahedron, composed of two four-sided pyramids applied base to base, each of the sides of which is an equilateral triangle‡. In some cases two opposite sides of the pyramids are broader than the other two; and sometimes the edges of the octahedron

Crystals.

* *Jour. de Min.* No xxviii. 279.

† See Kirwan's *Min.* i. 253.—Romé de Lisle, ii. 224.—Klaproth, *Beob. der Berlin*, iii. 336. and Beitrage, ii. 1.—Vauquelin, *Ann. de Chim.* xxvii. 3. and xxxi. 141.—Brochant, i. 202.—Hauy, ii. 496.—Bournon, *Phil. Trans.* 1802, p. 304.

‡ This octahedron is usually distinguished either by the epithet *regular* or *aluminiform*, because it is the well-known form of crystals of alum.

are wanting, and narrow faces in their place. For figures and descriptions of these, and other varieties of these crystals, the reader is referred to *Romé de Lisle* and the *Abbé Estner**. It occurs also in tetrahedrons, in rhomboids whose faces have angles of 120° and 60°, in rhomboidal dodecahedrons, and in four-sided prisms terminated by four-sided pyramids†. Class I. Genus III. Am.

The texture of the spinell is foliated. Fracture conchoidal. Its lustre is 3. Transparency 2 to 4. It causes a single refraction. Hardness 13. Specific gravity 3.570‡ to 3.625§. Colour red, of various shades; sometimes also blue, green, and yellow. The constituents of the spinell are, according to Properties.

Composition.

Vauquelin,	Klaproth,
86.00 alumina	76 alumina
8.50 magnesia	16 silica
5.25 chromic acid	8 magnesia
	1.5 oxide of iron
99.75	101.5

The ancients seem to have classed this stone among their hyacinths¶.

Sp. 2. Ceylanite.

Pleonaste of Hauy**.

The mineral denominated *ceylanite*, from the island of Ceylon, from which it was brought into Europe, had History.

* *Crystall.* ii. 226.—Estner's *Miner.* 73.
† Bournon.
‡ Klaproth.
§ Hatchette and Greville.
‖ *Ann. de Chim.* xxvii. 15.
¶ Plinii, lib. xxxvii. c. 9.
** Brochant, ii. 525.—Hauy's *Miner.* iii. 17.—Bournon, *Phil. Trans.* 1802, p. 318.

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been observed by Romé de Lisle *; but was first described by La Metherie in the *Journal de Physique* for January 1793.

It is most commonly found in rounded masses; but sometimes slso crystallized. The primitive form of its crystals is a regular octahedron: it often occurs under this form, but more commonly the edges of the octahedron are wanting, and small faces in their place†.

Properties.

The fracture of the ceylanite is conchoidal‡. Its internal lustre is glassy. Usually opaque, except when in very thin pieces; sometimes perfectly transparent. Hardness 12. Specific gravity from 3·7647§ to 3·793‖. Colour of the mass black; of very thin pieces deep green; sometimes red; sometimes dusky yellow, bluish green, and sky blue. Powder greenish grey. According to the analysis of Descotils, the ceylanite is composed of . . . . . 68 alumina

Composition.

16 oxide of iron
12 magnesia
2 silica

98¶

There is a striking resemblance between this mineral and the spinell. Probably they are merely varieties of the same species.

Genus IV. S.

This genus contains four species; namely quartz,

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* *Crystallog.* iii. 180. Note 21.

† Hauy, *Jour. de Min.* No. xxxviii. 264. ‡ Ibid. 263.

§ Hauy. ‖ Descotils. ¶ *Ann. de Chm.* xxiii. 11.

Class I. Genus IV. S.

chrysoprase, flint, and opal. The first, when pure, contains nothing but crystallized silica; the second, besides that earth, contains always some oxide of nickel, to which it owes its colour; and the third and fourth species are combinations of silica with different portions of water,

Sp. 1. Quartz *.

This stone, which is very common in most mountainous countries, is sometimes crystallized, and sometimes amorphous. The primitive form of its crystals, according to Mr Hauy, is a rhomboidal parallelopiped; the angles of whose rhombs are 94° and 86°; so that it does not differ much from a cube†. The most common variety is a dodecahedron, composed of two six-sided pyramids, applied base to base, whose sides are isosceles triangles, having the angle at the vertex 40°, and each of the angles at the base 70°; the inclination of a side of one pyramid to the contiguous side of the other pyramid is 104°. There is often a six-sided prism interposed between the two pyramids, the sides of which always correspond with those of the pyramids ‡. For a description and figure of the other varieties of quartz crystals, and for a demonstration of the law which they have followed in crystallizing, we refer the reader to *Romé de Lisle* § and *Mr Hauy* ||. Crystals.

The texture of quartz is more or less foliated. Frac-

* Kirwan's *Min.* i. 241.—Hauy, ii. 406.—Brochant, i. 239.

† *Jour. de Min.* No. xxviii. 255.

‡ *Crystallog.* ii. 71. § Ibid.

|| *Mem. Par.* 1786, p. 78.; and *Minerologie*, ii. 407. See also Lametherie, *Jour. de Phys.* xlii 470.

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ture conchoidal or splintery. Its lustre varies from 3 to 1, and its transparency from 4 to 1; and in some cases it is opaque. It causes a double refraction. Hardness from 10 to 11. Specific gravity from 2.64 to 2.67, and in one variety 2.691. Its colour and appearance are exceedingly various: this has induced mineralogists to divide it into numerous varieties. The common division is into five subspecies.

Amethyst.

1. Amethyst. Colour violet, of different degrees of intensity; sometimes greenish. Commonly found in crystals in the hollow cavities of agates. Composed, according to Rose, of

97.50 silica
0.25 alumina
0.50 oxide of iron and manganese

98.25

Rock crystal.

2. Rock crystal. Colourless; or white with different shades of grey, yellow, brown, and red. Usually crystallized in the hollows of veins. Transparency 3, 4. Composed, according to Bergman of

93 silica
6 alumina
1 lime

100

Rosy quartz.

3. Milky and rosy red quartz.—Colour usually red. Always in mass, never crystallized. Lustre greasy. Transparency 2, 3. Found in Bavaria and Finland. Supposed to contain manganese.

Quartz.

4 Common quartz. A constituent of many mountains. Colours exceedingly numerous, white, grey, brown, yellow, red, green of various shades. Usually amorphous; sometimes crystallized. Transparency

Class I. Gen. IV. S.

1, 2. It is the transparency chiefly that distinguishes it from rock crystal.

Prase.

5 Prase. Usually leek green; sometimes olive and pistachio green. Commonly in mass; rarely crystallized. Transparency 2.

Sp. 2. Chrysoprase *.

Properties.

This mineral, which is found in different parts of Germany, particularly near Kosemütz in Silesia, is always amorphous. Its fracture is either even or inclining to the splintery. Scarcely any lustre. Transparency 2 to 3. Hardness 10 to 12. Specific gravity 2.479. Colour green. In a heat of 130° Wedgewood it whitens and becomes opaque.

Composition.

A specimen of this stone, analysed by Mr Klaproth, contained

96.16 silica
1.00 oxide of nickel
0.83 lime
0.08 alumina
.08 oxide of iron

98.15†

Sp. 3. Flint ‡.

Pyromachus.—Pierre a fusil.

This stone, which has become so necessary in modern

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* Kirwan's *Min.* i.—Lehmann, *Mem. Berlin*, 1755, p. 202.—Klaproth, Beitrage, ii. 127.—Brochant, i. 280.—Hauy, ii. 426.

† Beitrage, ii. 153.

‡ Kirwan's *Min.* i. 301.—Brochant, i. 263 —Hauy, ii. 427.—Dolomieu, *Jour. de Min.* No. xxxiii. 693. and Salivet, ibid. 713. These last gentlemen give the only accurate account of the method of making gun flints.

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war, is found in pieces of different sizes, and usually of a figure more or less globular, commonly among chalk, and often arranged in some kind of order.

Properties.

Its texture is compact. Its fracture, smooth conchoidal. Lustre, external 0, the stones being always covered by a white crust; internal 1, inclining to greasy. Transparency, 2; when very thin, 3. Hardness, 11. Specific gravity, from 2.58 to 2.63. Colour varies from honey yellow to brownish black. Very brittle, and splits into splinters in exery direction. Two pieces of flint rubbed smartly together phosphoresce, and emit a peculiar odour. When heated it decrepitates, and becomes white and opaque. When exposed long to the air it often becomes covered with a white crust. A specimen of flint analysed by Klaproth contained . . . . . 98.00 silica,

Composition.

.50 lime,
.25 alumina,
0.25 oxide of iron,
1.00 water.

100.00 *

Vauquelin obtained from another,

97 silica,
1 alumina and iron.

98

Another specimen analysed by Dolomieu was composed of 97 silica,
1 alumina and oxide of iron,
2 water

100 †

* Beitrage, i. 46. † *Jour. de Min.* No. xxxiii. 702.

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The white crust with which flint is enveloped consists of the same ingredients, and also a little carbonat of lime. Dolomieu discovered that water is essential to flint; for when it is separated by heat the stone loses its properties*.

Gun flints.

The manufacture of gun flints is chiefly confined to England and two or three departments in France. The operation is exceedingly simple: a good workman will make 1000 flints in a day. The whole art consists in striking the stone repeatedly with a kind of mallet, and bringing off at each stroke a splinter, sharp at one end and thicker at the other. These splinters are afterwards shaped at pleasure, by laying the line at which it is wished they should break, upon a sharp iron instrument, and then giving it repeatedly small blows with a mallet. During the whole operation the workman holds the stone in his hand, or merely supports it on his knee†.

Sp. 4. Opal‡.

This stone is found in many parts of Europe, especially in Hungary, in the Crapacks near the village of Czennizka. When first dug out of the earth it is soft, but it hardens and diminishes in bulk by exposure to the air. The substance in which it is found is a ferrugenous sand-stone §.

Properties.

The opal is always amorphous. Its fracture is con-

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* *Jour de Min.* No. xxxiii. 702. † Ibid.

‡ Delius, *Jour. de Phys.* xliv. 45.

§ Kirwan's *Min.* i. 289.—Hauy, *Jour. de Hist. Nat.* ii. 9.—Delius, *Jour. de Phys.* xliv. 45.—Brochant, i. 341 —Hauy, ii 434.

choidal. Commonly somewhat transparent. Hardness from 6 to 9. Specific gravity from 1.958 to 2.540. The lowness of its specific gravity, in some cases, is to be acribed to accidental cavities which the stone contains. These are sometimes filled with drops of water. Some specimens of opal have the property of emitting various coloured rays, with a particular effulgency, when placed between the eye and the light. The opals which possess this property are distinguished by lapidaries by the epithet *oriental;* and often by mineralogists by the epithet nobilis. This property rendered the stone much esteemed by the ancients. Opals acquire it by exposure to the sun. Werner has divided this species into five subspecies.

Subspecies.

Noble,

1. Noble opal.—Lustre internal, glassy, 3. Tranparency 2, sometimes 3. Hardness, 6 to 7. Colour, usually light bluish white. When its position is varied it reflects the light of various bright colours. Brittle. Specific gravity 2.114. Does not melt before the blow pipe. When heated it becomes opaque, and sometimes is decomposed by the action of the atmosphere. Hence it seems to follow that water enters essentially into its composition. A specimen of this variety, analysed by Klaproth, contained

90 silica,
10 water.

100*

Common.

2. Common opal.—Fracture, imperfectly conchoidal. Lustre, external and internal, glassy or greasy. Transparency 2 to 3. Hardness, 7 to 9. Its colours are

* Beitrage, ii. 153

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very various; milk white, yellows, reds, greens of different kinds. Infusible by the blow-pipe

Specimens of this variety sometimes occur with rifts: these readily imbibe water, and therefore adhere to the tongue. Some opals gradually become opaque, but recover their transparency when soaked in water by imbibing that fluid. They are then called *hydrophanes*, or *oculi mundi*. The constituents of the common opal, as ascertained by Klaproth, are

Opal of Kosemutz,	Opal of Telkobanya,
98.75	93.5 silica
0.1	1.0 oxide of iron
0.1	0.0 alumina
0.0	5.0 water.
98.95	99.5 *

3. Semi-opal. *Menilites.*—Colours various shades of white, grey, yellow, red, brown; often mixed together. Lustre, 2 to 3, glassy, sometimes greasy. Fracture imperfectly conchoidal. Transparency 1 to 2, very seldom 3. Brittle. Sometimes adheres to the tongue. Specific gravity 2.540. Infusible before the blowpipe. Its constituents, as ascertained by Klaproth, are,

Semi-opal.

Semiopal of Telkobanya,	Of Menal-Montant,
43.5	85.5 silica
47.0	0.5 oxide of iron
7.5	11.0 water
	1.0 alumina
98.0	0.5 lime
	98,5 †

* Beitrage, ii. 164 and 169.

† Ibid.

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Wood-opal,

4. Hotz-opal or Wood-opal.—Colours, various shades of white, grey, brown, yellow, red. Found in large pieces, which have the form of wood. Lustre glassy, sometimes greasy, 2, 1. Fracture in one direction conchoidal, in another exhibiting the texture of wood. Usually opaque, sometimes its transparency is 1, seldom 2. Brittle. Considered as fragments of wood impregnated with semiopal.

Cat's eye.

5. Under the opal may be placed also the mineral known by the name of *cat's eye*. It comes from Ceylon, and is seldom seen by European mineralogists till it has been polished by the lapidary. Mr Klaproth has described a specimen which he received in its natural state from Mr Greville of London. Its figure was nearly square, with sharp edges, a rough surface, and a good deal of brilliancy.

Its texture is imperfectly foliated. Lustre greasy, 2. Transparency 3 to 2. Hardness 10. Specific gravity 2.625 to 2.66. Colour grey; with a tinge of green, yellow, or white: or brown, with a tinge of yellow or red. In certain positions it reflects a splendid white, as does the eye of a cat; hence the name of this stone.

Two specimens, analysed by Klaproth, the first from Ceylon, the other from Malabar, were composed of

95.00	94.50 silica
1.75	2.00 alumina
1.50	1.50 lime
0.25	0.25 oxide of iron
98.5 *	98.25 †

* Beitrage, i. 94. † Ibid. p. 96

If we believe Cordier, the cat's eye is nothing else than a mixture of asbestus in a small proportion with quartz *.

Genus V. Zs.

This genus comprehends combinations of silica with zirconia. Only two minerals are known, composed chiefly of these earths, the *zircon* and the *hyacinth*; and both of them have been comprehended under one species by Hauy under the name of *zircon*, because the primitive form of their crystals is the same.

Sp. 1. Zircon †.

Jargon—Hyacinth.

This stone is brought from Ceylon, and found also in France, Spain, and other parts of Europe. It is commonly crystallized. The primitive form of its crystals is an octahedron, composed of two four-sided pyramids applied base to base, whose sides are isosceles triangles. The inclination of the sides of the same pyramid to each other is 124° 12′; the inclination of the sides of one pyramid to those of another 82° 50′. The solid angle at the apex is 73° 44′ ‡. The varieties of the crystalline forms of zircon amount to seven. In some cases there is a four-sided prism interposed between the pyramids of the primitive form; sometimes all the angles of this prism are wanting, and two small triangular faces in place of each; sometimes the crystals are dodecahedrons, composed of a flat four-sided prism

Crystals.

* *Jour. de Phys.* lv 47. † Kirwan, i. 257. and 333.

‡ Hauy, *Jour. de Min.* No. xxvi. 91.

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with hexagonal faces, terminated by four-sided summits with rhomboidal faces; sometimes the edges of this prism, sometimes the edges where the prism and summit join, and sometimes both together, are wanting; and we find small faces in their place. For an accurate description and figure of these varieties, the reader is referred to Hauy.

Properties.

The texture of the zircon is foliated. Fracture imperfectly conchoidal. Internal lustre 3, glassy. Transparency from 4 to 2. Causes a very great double refraction. Hardness from 10 to 16. Specific gravity from 4.615 to 4.383. Colours various, commonly reddish or yellowish; sometimes it is limpid. Before the blowpipe it loses its colour, but not its transparency. With borax it melts into a transparent glass. Infusible with fixed alkali and microcosmic salt.

Varieties.

1. The variety formerly called *hyacinth* is of a yellowish red colour, mixed with brown. Its surface is smooth. Its lustre 3. Its transparency 3 to 4.

2. The variety formerly called *jargon of Ceylon* is either grey, greenish, yellowish brown, reddish brown, or violet. It has little external lustre. It is sometimes nearly opaque.

Composition.

The first variety, according to the analysis of Vauquelin, is composed of

64.5	zirconia
32.0	silica
2.0	oxide of iron
98.5*	

* Hauy, *Jour. de Min.* No. xxvi. p. 106.

A specimen analysed by Klaproth contained

70.0 zirconia
25.0 silica
0 5 oxide of iron

95·5*

The second variety, according to Klaproth, who discovered the component parts of both these stones, contains . . . . . 68.0 zirconia
31.5 silica
0.5 nickel and iron

100.0†

Genus VI. Sa.

This genus comprehends the minerals composed of silica and alumina, into which silica enters in the greatest proportion. Now as these two earths are by far the most abundant, and have a strong affinity for each other, it is natural to expect that many minerals exist formed of them chiefly. This genus accordingly is very large. Many of the species, however, are rather mechanical mixtures than chemical compounds; and accordingly, though they consist chiefly of silica, they exhibit the properties of alumina, because that earth is in the state of greatest fineness. The genus, then, naturally subdivides itself into two heads: The first comprehends those minerals which have the appearance of

* Beitrage, i. 231. † Ibid. i. 21

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chemical compounds; the second, those which are only mixtures.

Division I. Stony.

Sp. 1. Shorlite.

Shorlform-beryl of Werner—*Leucolite* of Daubenton—*Pyenite* of Hauy.

Properties.

This stone, which received its name from Mr Klaproth, is generally found in oblong masses, which when regular are six-sided prisms, inserted in granite. Its texture is foliated. Fracture uneven. Lustre 2, glassy. Transparency 2 to 1. Hardness 9 to 10. Easily broken. Specific gravity 3·53. Colour greenish or yellowish white; sometimes sulphur yellow. Not altered by heat. According to the analysis of Klaproth, it is composed of

Composition.

50	alumina
50	silica
100	*

According to Vauquelin, of

52.6	alumina
36.8	silica
3.3	lime
1.5	water
94.2	†

Sp. 2. Hornstone ‡.—*Chert.*

This stone is usually amorphous; occurring some-

* Crell's *Annals*, 1788, i. 390. † Hauy, iii. 237.

‡ Kirwan's *Min.* i. 303.—Baumer, *Jour. de Phys.* ii. 154. and Monnet, Ibid. 331.—Wiegleb, Crell's *Annals*, 1788, p. 46. and 135.—*Jour. de Phys.* liii. 239.—Brochant, i. 25.

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times in mass, sometimes in round balls. Fracture splintery, and sometimes conchoidal. Lustre 0. Transparency 1 to 2. Hardness 7 to 9. Specific gravity 2.699 to 2.708. Colour usually greyish blue: but hornstone occurs also of the following colours; grey, red, blue, green, and brown of different shades. Sometimes different colours appear in the same mineral.

Composition.

According to Kirwan, it is composed of

72 silica
22 alumina
6 carbonat of lime

100*

Werner comprehends under this species the *Holzstein* of the Germans; which is a mineral consisting of wood impregnated with hornstone.

Species 3. Pitchstone.

This stone, which occurs in different parts of Germany, France, and other countries, has obtained its name from some resemblance which it has been supposed to have to pitch. Is most usually in amorphous pieces of different sizes.

Properties.

Its fracture is conchoidal and uneven, and sometimes approaches the splintery. Lustre greasy, from 3 to 1. Transparency 2 to 1, sometimes 0. Hardness 8 to 10. Exceedingly brittle; it yields even to the nail of the finger. Specific gravity 2.314† to 1.645‡. Its colours are numerous, greyish black, bluish grey, green, red, yellow of different shades. Sometimes several of these

* Kirwan's *Min.* 305. † Bumenbach. ‡ Klaproth.

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Composition.

colours appear together in the same stone. A specimen of pitch-stone, analysed by Mr Klaproth, contained

73.00 silica
14.50 alumina
1.00 lime
1.00 oxide of iron
0.10 oxide of manganese
1.75 soda
8.50 water

99.85 *

Sp. 4. Chalcedony †.

This stone is found abundantly in many countries, particularly in Iceland and the Faro islands. It is most commonly amorphous, stalactitical, or in rounded masses; but it occurs also in pseudo-crystals. Surface rough. Fracture even or conchoidal. Lustre external 1; internal 2. Somewhat transparent. Hardness 10 to 11. Specific gravity 2.615 to 2.700. Brittle.

Composition.

According to Bergman, the chalcedony of Faro is composed of

84 silica
16 alumina, mixed with iron

100

Varieties.

Variety 1. Common chalcedony. Fracture even, inclining to conchoidal. Transparency 2 to 3; sometimes 1. Its colours are various; it is most commonly

* Beitrage, iii. 265.

† Brochant, i. 268. Kirwan, i 298. Hauy, ii. 425.

greyish, with a tint of yellow, green, blue, or pearl; often also white, green, red, yellow, brown, black, or dotted with red. When striped white and black, or brown, alternately, it is called *onyx*; when striped white and grey, it is called *chalcedonix*. Black or brown chalcedony, when held between the eye and a strong light, appears dark red.

Variety 2. Cornelian.—Fracture conchoidal. Transparency 3 to 1; often cloudy. Its colours are various shades of red, brown, and yellow. Several colours often appear in the same mass. The stones called *agates* are usually referred to this species. The name has been given to different hard stones capable of a fine polish; but chalcedony forms the basis of the greater number. The varieties in their colours, transparency, &c. have given occasion to their being known under a great variety of names.

Sp. 5. Plasma *.

Colour green, of different shades; often spotted and striped. Found in mass, in angular fragments, and in round pieces, often encrusted with talc. Lustre 2, greasy—Fracture, conchoidal—Transparency 2, sometimes 3—Hardness equal to that of chalcedony. This mineral is found in Italy, where it has been long known by the name of Plasma. It was considered as a variety of chalcedony, till Werner made it a distinct species.

Sp. 6. Heliotrope †.

Colour different shades of green, often stained or

* Brochant, i. 278.

† Kirwan, i. 314. Brochant, i. 276.

striped oilve, yellow, red. Found in mass, and in angular pieces—Lustre internal 2; greasy—Fracture conchoidal—Transparency 1, sometimes 2—Hardness 9—Specific gravity 2.633—Brittle—Infusible before the blow-pipe. It comes usually from the east, and may be considered as a chalcedony passing into a jasper.

Sp. 7. Jasper *.

This stone is an ingredient in the composition of many mountains. It occurs usually in large amorphous masses, sometimes in rounded or angular pieces. Its fracture is conchoidal. Lustre from 2 to 0. Either opaque, or its transparency is 1. Hardness 9 to 10. Specific gravity from 2.3 to 2.7. Its colours are various. When heated, it does not decrepitate. It is usually divided into 4 subspecies.

Subspecies.

1. Egyptian pebble.—This variety is found chiefly in Egypt. It usually has a spheroidal or flat rounded figure, and is enveloped in a coarse rough crust. Opaque, or transparency 1. Hardness 10. Specific gravity 2.564 to 2.6 It is chiefly distinguished by the variety of colours, which always exist in the same specimen, in concentric stripes or layers. These colours are, different browns and yellows, greens, &c.

2. Striped jasper.—This variety is also distinguished by concentric stripes or layers of different colours: these colours are, yellow, brownish red, and green. It is distinguished from the last variety by its occurring in large amorphous masses, and by the disposition of its stripes.

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* Kirwan's *Min.* i. 309.—Borral, *Hist. Natur. de Corse.*—Hańkel, *Act. Acad. Nat. Curios.* v. 339.—Brochant, i. 332.—Hauy.

3. Porcelain jasper. So called because its fracture presents the appearance of porcelain. Its colours are, various shades of grey, yellow, red, brown, green, mixed together. Found in mass, and in rounded pieces. Internal lustre, 1, 2—Greasy. Fracture imperfectly conchoidal—Opaque—Hardness 9—Brittle. According to Rose it is composed of

60.75	silica
27.25	alumina
3.00	magnesia
2.50	oxide of iron
3.60	potass
97.10	

Found in the neighbourhood of pseudo volcanoes, supposed to have been altered by the action of fire.

4. Common jasper.—Specific gravity from 2.53 to 2.7. Its colours are, different shades of white, yellow, red, brown, and green; often variegated, spotted, or veined, with several colours.

Division II. Earthy.

Sp. 8. Tripoli *.

This mineral is found sometimes in an earthy form, but more generally indurated. Its texture is earthy— Properties. Lustre 0—Generally opaque—Hardness 4, to 7—Specific gravity 2.080 to 2.529—Absorbs water—Feel, harsh dry—Hardly adheres to the tongue—Takes no polish from the nail—Does not stain the fingers—Colour

* Brochant, i. 380. Kirwan, i. 202.

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generally pale yellowish grey, also different kinds of yellow, brown, and white.

It contains, according to Hasse, 90 parts of silica, 7 alumina, and 3 of iron. A mineral belonging to this species was analysed by Klaproth, and found to contain

Composition.

66.5 silica
7.0 alumina
2.5 oxide of iron
1.5 magnesia
1.25 lime
19.0 air and water

97 75

Sp. 9. Porcelain earth*.

This mineral is supposed to originate from decomposed felspar. Its texture is earthy. Its lustre 0. Opaque. Hardness 4. Specific gravity from 2.23 to 2.4. Colour white, sometimes with a shade of yellow or red. Adheres to the tongue. Feels soft. Falls to powder in water. Stains paper. Does not fuse *per se*. The porcelain earth of Limoges contains, according to

Composition.

Hassenfratz,	Vauquelin,
62 silica	55 silica
19 alumina	27 alumina
12 magnesia	2 lime
7 sulphat of barytes	0.5 iron
	14 water
100†	98.5‡

A specimen, analysed by Mr Wedgewood, contained

* Kirwan, i. 178.—Brochant, i. 320.
† *Ann. de Chim.* xiv. 144.
‡ *Bull. Phil.* No. 26.

60 alumina
20 silica
12 air of water

92

This earth is employed in the manufacture of porcelain, either by itself or mixed with other earths. That of Limoges requires no addition. In China it is known by the name of *kaolin*.

Sp. 10. Common clay.

Clay is a mixture of alumina and silica in various proportions. The alumina is in the state of an impalpable powder; but the silica is almost always in small grains, large enough to be distinguished by the eye. Clay, therefore, exhibits the character of alumina, and not of silica, even when this last ingredient predominates. The particles of silica are already combined with each other; and they have so strong an affinity for each other, that few bodies can separate them; whereas the alumina, not being combined, readily displays the characters which distinguish it from other bodies. Besides alumina and silica, clay often contains carbonat of lime, of magnesia, barytes, oxide of iron, &c. And as clay is merely a mechanical mixture, the proportion of its ingredients is exceedingly various.

Its texture is earthy. Lustre 0. Opaque. Hardness 3 to 6. Specific gravity 1.8 to 2.68. Adheres slightly to the tongue. Often feels greasy. Falls to powder in water. Colour, when pure, white; often tinged blue or yellow. Properties.

Subspecies 1. Potters clay.

Hardness 3 to 4. Specific gravity 1.8 to 2. Stains Subspecies.

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the fingers slightly. Acquires some polish by friction. Colour white; often with a tinge of yellow or blue; sometimes brownish, greenish, reddish. Totally diffusible in water; and, when duly moistened, very ductile. A specimen from Dreux, analysed by Vauquelin, contained . . . . . 43·5 silica

33·2 alumina
3·5 lime
1.0 iron
18.0 water

99·2*

Very common in strata. Tobacco pipe-clay is a variety of this subspecies.

Subspecies 2. Indurated clay.

Hardness 5 to 6. Does not diffuse itself in water, but falls to powder. Discovers but little ductility. Colours grey, yellowish, bluish, greenish, reddish, brownish.

Subspecies 3. Shistose clay.

Structure slaty. Specific gravity from 2.6 to 2.68. Feels smooth. Streak white or grey. Colour commonly bluish, or yellowish grey; sometimes blackish, reddish, greenish. Found in strata, usually in coal mines.

This variety is sometimes impregnated with bitumen. It is then called bituminous *shale*.

Sp. 11. Cimolite†.

Found by Hawkins in the isle of Argentiers in the

* *Bull. Philomat.* No. 26.

† Brochant, i. 329.—Klaproth, i. 299.

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Archipelago, where it is used for whitening stuffs. It was mentioned by Pliny under the name of *cimolia*. Colour pearl grey: when exposed to the air becomes reddish. Texture earthy. Fracture uneven. Opaque. Does not stain. Adheres strongly to the tongue. Soft. Difficultly broken. Specific gravity 2.000. Becomes white before the blow-pipe. According to the analysis of Klaproth, it is composed of

Composition.

63.00 silica
23.00 alumina
1.25 iron
12.00 water

99.25

Sp. 12. Poliershiefer*.

Properties.

Found chiefly at Menil Montant near Paris. Colour grey; often reddish; sometimes spotted or striped brownish black and lemon yellow. Found in strata. Lustre 0. Texture earthy. Fracture conchoidal. Structure shistose. Transparency 1. Very soft. Easily broke. Adheres strongly to the tongue. Feel harsh. Specific gravity 2.08. Absorbs water with avidity. Melts to a blackish slag. Constituents

Composition.

66.50 silica
7.00 alumina
1.50 magnesia
1.25 lime
2.50 oxide of iron
19.00 water

97·75†

* Klaproth, ii. 170.—Brochant, i. 376. † Klaproth.

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Sp. 13. Black chalk, or Zeichenschiefer *.

Structure slaty. Texture earthy. Fragments splintery. Lustre o. Opaque. Hardness 5. Specific gravity 2.144 to 2.77. Colour black. Streak black.

Feels smooth. Adheres slightly to the tongue. Does not moulder in water. When heated to redness it becomes reddish grey.

According to Wiegleb, it is composed of

64.50 silica
11.25 alumina
11.00 charcoal
2.75 oxide of iron
7.50 water

97.00 †

Sp. 14. Fullers earth ‡.

Texture earthy. Structure sometimes slaty. Fracture imperfectly conchoidal. Lustre o. Opaque. Hardness 4. Receives a polish from friction. Does not adhere to the tongue. Feels greasy. Colour usually light green.

A specimen from Hampshire, analysed by Bergman, contained . . . . . 51.8 silica

Composition.

25.0 alumina
3.3 carbonat of lime
3.7 oxide of iron
0.7 carbonat of magnesia
15.5 moisture

100.0 §

* Kirwan, i. 112.—Brochant, i. 391.
† *Ann. de Chim.* xxx. 13.
‡ Kirwan, i. 184.—Brochant, i. 464.
§ *Opusc.* iv. 159.

This earth is used by fullers to take the grease out of their cloth before they apply soap. It is essential to fullers earth that the particles of silica be very fine, otherwise they would cut the cloth. Any clay, possessed of this last property, may be considered as *fullers earth*; for it is the alumina alone which acts upon the cloth, on account of its strong affinity for greasy substances.

Genus VII. Sai.

The minerals belonging to this genus are composed of silica, alumina, and the oxide of iron: The proportion of the silica exceeds that of the other ingredients.

Sp. 1. Mica*.

This stone forms an essential part of many mountains, and has been long known under the names of *glacies mariæ* and *Muscovy glass*. It consists of a great number of thin laminæ adhering to each other, sometimes of a very large size. Specimens have been found in Siberia nearly $2\frac{1}{2}$ yards square†.

Properties.

It is sometimes crystallized: Its primitive form is a rectangular prism, whose bases are rhombs, with angles of 120° and 60°: Its integrant molecule has the same form. Sometimes it occurs in rectangular prisms, whose bases also are rectangles, and sometimes also in

* Kirwan, i. 210.—Gmelin, *Nov. Com. Petropol.* xii. 549.—Hauy. iii. 208.—Brochant, i. 402.

† *Hist. General de Voyages*, t. xviii. 272. quoted by Hauy, *Jour. de Min.* No. xxviii. 299.

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short six-sided prisms; but it is much more frequently in plates or scales of no determinate figure or size*.

Its texture is foliated. Its fragments flat. The lamellæ flexible, and somewhat elastic. Lustre metallic, from 3 to 4. Transparency of the laminæ 3 or 4, sometimes only 2†. Hardness 6. Very tough. Often absorbs water. Specific gravity from 2.6546 to 2.9342. Feels smooth, but not greasy. Powder feels greasy. Colour, when purest, silver white or grey; but it occurs also yellow, greenish, reddish, brown, and black. Mica is fusible by the blow-pipe into a white, grey, green, or black enamel; and this last is attracted by the magnet‡. Spanish wax rubbed by it becomes negatively electric§.

Composition.

A specimen of mica, analysed by Vauquelin, contained

50.00 silica
35.00 alumina
7.00 oxide of iron
1.35 magnesia
1.33 lime

94.68 ||

Mica has long been employed as a substitute for glass. A great quantity of it is said to be used in the Russian marine for panes to the cabin windows of ships; it is preferred, because it is not so liable as glass to be broken by the agitation of the ship.

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* Hauy, *Jour. de Min.* No. xxviii. 296.

† Black mica is often nearly opaque.

‡ Hauy, *Jour. de Min.* No. xxviii. p. 295. Bergman, however, found pure mica infusible *per se*.

§ Ibid. || Ibid.

Sp. 7. Talc*.

This stone has a very strong resemblance to mica, and was long considered as a mere variety of that mineral. It occurs sometimes in small loose scales, and sometimes in an indurated form.

Its texture is foliated. The lamellæ are flexible, but not elastic. Its lustre is from 2 to 4. Transparency from 2 to 4. Hardness 4 to 6. Specific gravity, when indurated, from 2.7 to 2.8. Feels greasy. Colour most commonly whitish or greenish. Spanish wax rubbed with it becomes *positively* electric†. Properties.

Variety 1. Scaly talc. *Talcite* of Kirwan.—This variety occurs under the form of small scales, scarcely cohering. Lustre 3 to 4. Pearly. Very light. Adheres to the fingers. When rubbed upon the skin, it gives it a gloss. Colour white, with a shade of red or green; sometimes leek green. Varieties.

Variety 2. Common talc. *Venetian talc.*—This variety often occurs in oblong nodules. Lustre nearly metallic, 4. Transparency 2 to 3; when very thin 4. Hardness 4 to 5. Colour white, with a shade of green or red; or apple green, verging towards silver white. By transmitted light green.

Variety 3. Shistose talc.—Its structure is slaty. Fracture hackly and long splintery. Easily crumbles when rubbed in the fracture. External lustre 2 to 3; internal 1; but sometimes, in certain positions, 3. Colour grey,

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* Kirwan, i. 150.—*Pott. Mem. Berl.* 1746, p. 65.—Hauy, iii. 252.—Brochant, i. 486.

† Hauy, *Jour. de Min.* No. xxviii. 291.

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with a shade of white, green, or blue. Becomes white and scaly when exposed to the air.

Composition.

A specimen of *common talc*, analysed by Mr Chenevix, contained

48.0 silica
37.0 alumina
6.0 oxide of iron
1.5 magnesia
1.5 lime
5.0 water

99.0 *

Sp. 3. Hornblende †.

Properties.

This mineral enters into the composition of many mountains. It is often amorphous, but frequently also crystallized. The primitive form of its crystals is a rhomboidal prism, the faces of which are inclined at angles of 124° 34′ and 55° 26′, and whose bases have angles of 122° 56′ and 57° 4′. The most common variety is a six-sided prism, terminated by trihedral or tetrahedral summits.

Subspecies 1. Common hornblende.

Subspecies.

Its texture is very conspicuously foliated. Fracture conchoidal. Fragments often rhomboidal. Lustre 2. Opaque. Hardness 5 to 9. Tough. Specific gravity 2.922 to 3.41. Colour black, blackish green, olive green, or leek green. Streak greenish. It neither becomes electric by friction nor heat ‡. Before the blowpipe it melts into a black glass. A specimen of black

* *Ann. de Chim.* xxviii. 200.

† Kirwan, i. 213.—Hauy, iii. 58.—Brochant, i. 415.

‡ Hauy, *Jour. de Min.* No. xxviii. 267.

hornblende, analysed by Mr Hermann, was composed of

37 silica
27 alumina
25 iron
5 lime
3 magnesia

97*

Subspecies 2. Basaltic hornblende.

This stone is found commonly in basaltic rocks; hence the name *basaltine*, which was imposed by Mr Kirwan. It is crystallized, either in rhomboidal prisms, or six or eight-sided prisms, terminated by three-sided pyramids. Its texture is foliated. Its fracture uneven. Lustre 3. Transparency, when in very thin plates, 1. Hardness from 9 to 10. Specific gravity 3.333. Colour black, dark green, or yellowish green. Streak white. Transmits a reddish yellow light. Before the blow-pipe it melts into a greyish-coloured enamel, with a tint of yellow†. A specimen, seemingly of this stone, analysed by Bergman, contained

58 silica
27 alumina
9 iron
4 lime
1 magnesia

99‡

* *Beob. der Berlin*, 5 Band. 317.
† Le Lievre, *Jour. de Min.* No. xxviii. 269.
‡ Bergman, iii. 207.

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Subspecies 3. Shistose hornblende.

Colour greenish black or deep green. Forms strata. Lustre 2, 3, common. Structure shistose. Texture radiated or fibrous. Opaque. Hardness 8. Brittle. Streak greenish grey. Moderately heavy. Gives an argillaceous smell when breathed upon. This mineral is often confounded with slate. In Sweden it is employed for covering houses.

Sp. 4. Obsidian *.

Iceland agate.

This stone is found either in detached masses, or forming a part of rocks. It has exactly the appearance of a black glass. It is usually invested with a grey or opaque crust. Its fracture is conchoidal. Its internal lustre 3. Glassy. Transparency 1. Hardness 10. Specific gravity 2.348. Colour black or greyish black: when in very thin pieces green. Very brittle. It melts into an opaque grey mass. According to Bergman, it is composed of

Composition.

69 silica
22 alumina
9 iron

100 †

Found in Iceland, Italy, &c.

Genus VIII. Asi.

This genus comprehends those minerals composed of

* Kirwan, i. 221.—Brochant, i. 288.—Hauy, iv. 494.
† Bergman, iii. 204.

alumina, silica, and the oxide of iron, which contain a greater proportion of alumina than of silica.

Class I. Genus VIII. Asi.

Sp. 1. Shorl.

Tourmaline of Hauy *.

No word has been used by mineralogists with less limitation than *shorl*. It was first introduced into mineralogy by Cronstedt, to denote any stone of a columnar form, considerable hardness, and a specific gravity from 3 to 3.4. This description applied to a very great number of stones; and succeeding mineralogists, though they made the word more definite in its signification, left it still so general, that under the designation of *shorl* almost 20 distinct species of minerals were included. Mr Werner first defined the word *shorl* precisely, and restricted it to one species of stones. It occurs commonly in granite, gneiss, and other similar rocks; often in mass, but very frequently crystallized. Primitive form of its crystals is an obtuse rhomboid; the solid angle at the summit of which is 139°, having rhombic faces, with angles of 114° 12′ and 65° 48′: But it usually occurs in 3, 6, 8, 9, or 12 sided prisms, terminated by 4 or 5 sided summits, variously truncated. For a description of which the reader is referred to *Hauy* † and *Bournon* ‡.

Crystals.

Subspecies 1. Black Shorl §.

Colour black. Found in mass, disseminated and crystallized. Crystals three-sided prisms, having their lateral edges truncated. Sometimes terminating in a

* Hauy, iii. 31. † *Miner.* iii. 34.

‡ *Phil. Trans.* 1802, p. 313.

§ Kirwan, i. 265.—Brochant, i. 226.

Book III. Chap. II. Properties.

pyramid. Lateral faces of the prism striated. Lustre 2. Vitreous. Fracture conchoidal. Opaque. Scratch grey. Hardness 10. Feel cold. Specific gravity from 3.054 to 3.092. It becomes electric by heat. When heated to redness, its colour becomes brownish red; and at 127° Wedgewood, it is converted into a brownish compact enamel *. According to Wiegleb, it is composed of . . . . . 41.25 alumina

Composition.

34.16 silica
20.00 iron
5.41 manganese

100.82†

Subspecies 2. Electric shorl‡.

Tourmaline of Kirwan.

This stone was first made known in Europe by specimens brought from Ceylon; but it is now found frequently forming a part of the composition of mountains. It is sometimes in amorphous pieces, but much more frequently crystallized in three or nine-sided prisms, with four-sided summits.

Properties,

Colour usually green; sometimes brown, red, blue. Found in mass, in grains, and crystallized. Crystals 3, 6, or 9 sided prisms, variously truncated. Faces usually striated longitudinally. Its texture is foliated.

* Kirwan's *Min.* i. 166.

† Crell's *Beitrage*, 1 Band. 4 Stuck. p. 21.

‡ Kirwan, i. 271.—Bergman, ii. 118. and v. 402.—Gerhard, *Mem. Berl.* 1777, p 14.—Hauy, *Mem. Par.* 1784, p. 270.—Wilson, *Phil. Trans.* xli. 308.—Æpinus, *Recueil sur la Tourmaline.*—See also La Porterie, *le Sapphir, l'Oeil de Chat, et la Tourmaline de Ceylon demasqués.*—Brochant, i. 228.

Its fracture conchoidal. Internal lustre 2 to 3. Glassy. Transparency 3 to 4; sometimes only 2*. Causes only single refraction†. Hardness 9 to 11. Specific gravity 3.05 to 3.155. Colour brown, often so dark that the stone appears black; the brown has also sometimes a tint of green, blue, red, or yellow. Class I. Genus VIII. Asi.

When heated to 200° Fahrenheit, it becomes electric; one of the summits of the crystal negatively, the other positively‡. It reddens when heated; and is fusible *per se* with intumescence into a white or grey enamel.

A specimen of the tourmaline of Ceylon, analysed by Vauquelin, was composed of

Composition.

40	silica
39	alumina
12	oxide of iron
4	lime
2.5	oxide of manganese
97.5§	

The *siberite* of Lermina, called *daourite* by Lamethérie, a mineral found in Siberia, is considered as merely a variety of shorl.

Sp. 2. Pinite.

Micarell of Kirwan‖.

This mineral has received its name from *Pini* in

* And when black only 1. It is always opaque when viewed in a direction parallel to the axis of the crystal.

† Hauy, *Jour. de Min.* No. xxviii. 265.

‡ Æpinus.

§ *Ann. de Chim.* xxx. 105.

‖ *Mineral.* i. 212.—Brochant, i. 456.

Book III. Chap. II.

Saxony, where alone it has been found in a granite. Its colour is reddish brown or black. Always in crystals; either rhomboidal prisms, or six-sided prisms; sometimes entire; sometimes having their alternate lateral edges truncated, sometimes the whole. Surface smooth and somewhat brilliant. Lustre internal o. Fracture uneven, passing to the conchoidal. Hardness 6. Specific gravity 2.980. At 153° Wedgewood it melts into a black compact glass, the surface of which is reddish *.

A specimen analysed by Klaproth contained

Composition.

63.00 alumina
29.50 silica
6.75 iron

99.25†

Sp. 3. Granatite ‡.

Staurotide of Hauy—*Pierre de Croix* of De Lisle—*Staurolithe* of Lametherie.

Granatite is found in Galicia in Spain, Brittanny in France, and at St Gothard. It is always crystallized in a very peculiar form; two six-sided prisms intersect each other, either at right angles or obliquely. Hence the name *cross-stone*, by which it was known in France and Spain §. Mr Hauy has proved, in a very ingenious manner, that the primitive form of the granatite is a rectangular prism, whose bases are rhombs, with angles of $129\frac{1}{2}°$ and $50\frac{1}{2}°$; and that the height of the prism is

Crystals.

* Kirwan's *Min.* i. 212.
† *Beitrage*, ii. 227.
‡ Brochant, ii. 496.—Hauy, iii. 93.
§ Romé de Lisle, ii. 435.

Class I. Genus VIII. Asi.

to the greater diagonal of a rhomb as 1 to 6; and that its integrant molecules are triangular prisms, similar to what would be obtained by cutting the primitive crystal in two, by a plane passing vertically through the shorter diagonal of the rhomboidal base. From this structure he has demonstrated the law of the formation of the cruciform varieties*. The colour of granatite is greyish or reddish brown. Specific gravity 3.2861. Hardness 12. Texture foliated. Usually opaque. Internal lustre 2. Glassy or greasy. Infusible before the blow-pipe. Two specimens, analysed by Vauquelin, gave the following constituents:

Composition.

From Brittanny.

44.00 alumina
33.00 silica
13.00 oxide of iron
3.84 lime
1.00 oxide of manganese

94.84†

From St Gothard.

47.06 alumina
30.59 silica
15.30 oxide of iron
3.00 lime

95.95‡

* *Ann. de Chim.* vi. 142.
† *Jour. de Min.* No. liii. p. 453.
‡ *Ann. de Chim.* xxx. 106.

Genus IX. Snaw.

Sp. 1. Pimelite.

The mineral distinguished by this name is an earthy substance, of an apple green colour, which accompanies the chrysopase of Tkosemütz. Klaproth has analysed it, and found it composed of the following ingredients.

35.00 silica
15.62 oxide of nickel
5.00 alumina
4.58 oxide of iron
1.25 magnesia
37.91 water

99.36 *

Genus X. Sap.

The minerals belonging to this genus are composed of silica and alumina, and contain besides a notable portion of potass. Whether the potass be an essential constituent, or merely mechanically interposed between the laminas of the minerals, it is impossible at present to decide. The latter is not unlikely; at least in some of the species, as certain varieties occur which contain no potass.

* *Jour. de Phys.* lii. 39.—Klaproth, ii. 139.

Class I. Genus X. SAP.

Sp. 1. Lepidolite *.

Lilalite.

This stone appears to have been first observed by the Abbé Poda, and to have been first described by De Born †. Hitherto it has only been found in Moravia in Germany, and Sudermania in Sweden ‡. There it is mixed with granite in large amorphous masses. It is composed of thin plates, easily separated, and not unlike those of mica §. Lustre pearly, 3. Transparency between 1 and 2. Hardness 4 to 5. Not easily pulverised ||. Specific gravity from 2.816 ¶ to 2.8549 **. Colour of the mass, violet blue; of the thin plates, silvery white. Powder white, with a tint of red ††. Before the blowpipe, it frothes, and melts easily into a white semitransparent enamel, full of bubbles. Dissolves in borax with effervescence, and communicates no colour to it ‡‡. Effervesces slightly with soda, and melts into a mass spotted with red. With microcosmic salt, it gives a pearl-coloured globule §§.

Properties.

This stone was first called lilalite from its colour, that of the *lily*. Klaproth, who discovered its component parts, gave it the name of *lepidolite* |||.

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* Kirwan, i. 208.— Karsten, *Beob. der Berlin*, 5 Band. 71.—Klaproth's *Beitrage*, i. 279. and ii. 191.—Brochant, i. 399.—Hauy, iv. 375.

† Crell's *Annals*, 1791, ii. 196. ‡ Beyer, *Ann. de Chim.* xxix. 108.

§ Le Lievre, *Jour. de Min.* No li. 219. || Ibid. ¶ Klaproth.

** Hauy. †† Le Lievre, *Jour. de Min.* No. li. 219. ‡‡ Ibid.

§§ Klaproth, *Ann. de Chim.* xxii. 37.

[|| That is, *scale stone*, or stone composed of scales: From λεπις, *the scale of a fish*, and λιθος, *a stone*.

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Composition.

It is composed of 53 silica
20 alumina
18 potass
5 fluat of lime
3 oxide of manganese
1 oxide of iron.

100*

Sp. 2. Leucite†.

Vesuvian of Kirwan—*White Garnet* of Vesuvius—*Amphigene* of Hauy.

This stone is usually found in volcanic productions, and is very abundant in the neighbourhood of Vesu-

Crystals. vius. It is always crystallized. The primitive form of its crystals is either a cube or a rhomboidal dodecahedron, and its integrant molecules are tetrahedrons; but the varieties hitherto observed are all polyhedrons. The most common has a spheroidal figure, and is bounded by 24 equal and similar trapezoids; sometimes the faces are 12, 18, 36, 54, and triangular, pentagonal, &c. For a description and figure of several of these, I refer the reader to Mr Hauy‡. The crystals vary from the size of a pin-head to that of an inch.

Properties. The texture of the leucite is foliated. Its fracture somewhat conchoidal. Lustre 3; when in a state of decomposition 0. Transparency 3 to 2; when decomposing 0. Hardness 8 to 10; when decomposing 5 to 6. Specific gravity from 2.455 to 2.490§. Colour white,

* Vauquelin, *Ann. de Chim.* xxx. 105.
† Kirwan, i. 285.—Brochant, i 188.—Hauy, ii. 559.
‡ *Jour. de Min.* No. xxvii. 185. § Klaproth.

Class I. Genus X. Sap.

or greyish white *. Its powder causes syrup of violets to assume a green colour †. Infusible by the blow-pipe. Gives a white transparent glass with borax.

It is composed, as Klaproth has shewn, of

Composition.

54 silica
23 alumina
22 potass

99 ‡

It was by analysing this stone that Klaproth discovered the presence of potass in the mineral kingdom; which is not the least important of the numerous discoveries of that accurate and illustrious chemist.

Leucite is found sometimes in rocks which have never been exposed to volcanic fire; and Mr Dolomieu has rendered it probable, from the substances in which it is found, that the leucite of volcanoes has not been formed by volcanic fire, but that it existed previously in the rocks upon which the volcanoes have acted, and that it was thrown out unaltered in fragments of these rocks §.

Sp. 3. Felspar ¶.

This stone forms the principal part of many of the highest mountains. It is commonly crystallized. Its primitive form is an oblique angled irregular parallelopiped. It usually occurs in rhomboidal prisms, or in

* Hence the name *leucite*, from λευκος, *white*.

† Vauquelin, *Jour. de Min.* No xxxix. 165.

‡ See *Jour. de Min.* No. xxvii. 194. and 201. and Klaproth's *Beitrage*, ii. 39.

§ *Jour. de Min.* No. xxxix. 177.

¶ Kirwan, i. 316. and *Jour. de Phys.* passim.—Hauy, ii. 590.—Brochant, i. 361.

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six or ten sided prisms terminated by irregular summits: for a precise description of which the reader is referred to Hauy. Its texture is foliated. Its cross fracture uneven. Fragments usually rhomboidal, and commonly smooth and polished on four sides. Lustre of the polished faces often 3, glassy or pearly. Transparency from 3 to 1. Hardness 9 to 10. Specific gravity from 2.437 to 2.7. Gives a peculiar odour when rubbed. It is made electric with great difficulty by friction. Fusible *per se* into a more or less transparent glass. When crystallized, it decrepitates before the blowpipe.

Properties.

Subspecies.

Subspecies 1. Common Felspar.

Common.

Lustre of the cross fracture 0; of the fracture in the direction of the laminæ, from 3 to 1. Transparency 2 to 1. Specific gravity 2.272 to 2.594. Colour most commonly flesh red; but often bluish grey, yellowish white, milk white, brownish yellow; and sometimes blue, olive, green, and even black. A specimen of green felspar from Siberia belonging to this subspecies, analysed by Vauquelin, contained

62.83 silica
17.02 alumina
16.00 potass
3.00 lime
1.00 oxide of iron

99.85 *

Subspecies 2. Compact Felspar.

Compact.

It is found in large masses. Texture foliated. Frac-

* *Ann. de Chim.* xxx. 106.

ture uneven, sometimes splintery. Lustre 1 to 2. Transparency 1. Hardness 10. Specific gravity 2.609. Colour sky blue, sometimes with a shade of green or yellow. Found near Kreiglach in Stiria.

Subspecies 3. Labradore Felspar.

Labradore.

This variety was discovered on the coast of Labradore by Mr Wolfe; and since that time it has been found in Europe. Found in round masses, and detached. Lustre 2 to 3. Transparency from 2 to 3. Specific gravity from 2.67 to 2.6925. Colour grey. In certain positions, spots of it reflect a blue, purple, red, or green colour.

Subspecies 4. Pure Felspar.

Moonstone—Adularia.

Adularia.

This is the purest felspar hitherto found. It occurs in Ceylon and Switzerland; and was first mentioned by Mr Pini. Lustre nearly 3. Transparency 2 to 3. Hardness 10. Specific gravity 2.559. Colour white; sometimes with a shade of yellow, green, or red. Its surface is sometimes iridescent. A specimen of Adularia, analysed by Vauquelin, yielded

64 silica
20 alumina
14 potass
2 lime

100

The whitish felspar called *petunze* yielded to the same chemist

74.0 silica
14.5 alumina
5.5 lime

94.0

Sp. 4. White Chlorite.

This is a mineral composed of brilliant scales of a silvery white colour, very soft, and when rubbed upon other bodies, leaving a powder resembling the scales of fish. Smell argillaceous. Water in which it is agitated becomes alkaline. Before the blowpipe, melts into a greenish white enamel. When calcined, loses 0.06 of its weight, and becomes reddish. It is composed of

Composition.

56 silica
18 alumina
8 potass
3 lime
4 oxides of iron and manganese
6 water

95*

Genus XI. Sag.

The minerals belonging to this genus are composed of silica combined with alumina and glucina.

Sp. 1. Emerald †.

Crystals.

This stone has hitherto been found almost always crystallized. The primitive form of its crystals is a regular six-sided prism; and the form of its integrant molecules is a triangular prism, whose sides are squares,

* Vauquelin, *Jour. de Phys.* lii. 245.

† Kirwan, i. 247. and 248.—Dolomieu, *Magazin Encyclopædique*, ii. 17. and 145; and *Jour. de Min.* No. xviii. 19.—Klaproth's *Beitrage*, ii. 12. —Brochant, i. 217.—Hauy, ii. 516.

and bases equilateral triangles*. The most common variety of its crystals is the regular six-sided prism, sometimes with the edges of the prism, or of the bases, or the solid angles, or both wanting, and small faces in their place†. The sides of the prism are generally channelled. Class I. Genus XI. SAG.

Its texture is foliated. Its fracture conchoidal. Lustre usually from 3 to 4. Transparency from 2 to 4. Causes a double refraction. Hardness 12. Specific gravity 2.65 to 2.775. Colour green. Becomes electric by friction, but not by heat. Its powder does not phosphoresce when thrown on a hot iron‡. At 150° Wedgewood it melts into an opaque coloured mass. According to Dolomieu, it is fusible *per se* by the blow-pipe §. Properties.

This mineral was formerly subdivided into two distinct species, the *emerald*, and *beryl* or *aqua marina*. Hauy demonstrated, that the emerald and beryl corresponded exactly in their structure and properties; and Vauquelin found that they were composed of the same ingredients: henceforth, therefore, they must be considered as varieties of the same species. Varieties.

The variety called *emerald* varies in colour from the pale to the perfect green. It comes chiefly from Peru; some specimens have been brought from Egypt. Dolomieu found it in the granite of Elba. When heated to 120° Wedgewood, it becomes *blue*, but recovers its colour when cold. A specimen, analysed by Vauquelin, was composed of Emerald.

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* Hauy, *Jour de Min.* No. xix. 72.

† Rome de Lisle, ii. 445. and Hauy, Ibid.

‡ Dolomieu, *Jour. de Min.* No. xviii. 19. § Ibid

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Composition.

64.60 silica
14.00 alumina
13.00 glucina
3.50 oxide of chromium
2.56 lime
2.00 moisture or other volatile ingredient

99.66 *

Beryl.

The *beryl* is of a mountain green colour, and sometimes blue, yellow, and even white: sometimes different colours appear in the same stone†. It is found in Ceylon, different parts of India, Brazil, and especially in Siberia and Tartary, where its crystals are sometimes a foot long‡. A specimen of beryl, analysed by Vauquelin, contained

Composition.

69 silica
13 alumina
16 glucina
1 oxide of iron
0.5 lime

99.5 §

It was by analysing this stone that Vauquelin discovered the earth which he called *glucina*.

Sp. 2. Euclase ‖.

Crystals.

This stone, which has lately been brought from Peru by Dombey, was at first confounded with the emerald on account of its green colour. The primitive form of its crystals is a rectangular prism, whose bases are

* *Ann. de Chim.* xxvi. 264. † Dolomieu, Ibid.
‡ Ibid. § *Ann. de Chim.* xxvi. 172.
§ Brochant, ii. 508.—Hauy, ii. 531.

squares; but it usually occurs in four-sided oblique prisms, whose edges are variously truncated. It is very brittle; sufficiently hard to scratch quartz. Texture foliated. Fracture conchoidal. Lustre 3, glassy. Causes double refraction. Specific gravity 3.0625. Fusible by the blowpipe into a white enamel. A small specimen, analysed by Vauquelin, yielded the following ingredients . . . . . 36 silica

Class I. Genus XII. Sab.

Composition.

23 alumina
15 glucina
5 oxide of iron

79 *

The loss, which amounts to 21, was probably owing to the presence of an alkali, which the smallness of the specimen analysed did not permit Vauquelin to ascertain.

Genus XII. Sab.

Sp. 1. Staurolite †.

Andreolite of Lametherie—*Hyacinthe blanche cruciforme*, var. 9. of Romé de Lisle—*Harmotome* of Hauy.

This stone has been found at Andreasberg in the Hartz. It is crystallized, and the form of its crystals has induced mineralogists to give it the name of *cross-stone*. Its crystals are two four-sided flattened prisms, terminated by four-sided pyramids, intersecting each other at right angles: the plane of intersection passing longitudinally through the prisms ‡. Sometimes these

Crystals.

* *Jour. de Phys.* lii. 317.

† Kirwan, i. 282.—Hauy iii. 191.—Brochant, i. 311.

‡ See also Gillot, *Jour. de Phys.* 1793, p. 1. and 2.

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prisms occur solitary. Primitive form, an octahedron with isosceles triangular faces. The faces of the crystals striated longitudinally.

Properties.

Its texture is foliated. Its lustre glassy, 2. Transparency from 1 to 3. Hardness 9. Brittle. Specific gravity 2.333 to 2.361. Colour milk white. When heated slowly, it loses 0.15 or 0.16 parts of its weight, and falls into powder. It effervesces with borax and microcosmic salt, and is reduced to a greenish opaque mass. With soda it melts into a frothy white enamel. When its powder is thrown on a hot coal, it emits a greenish yellow light *.

Composition.

A specimen analysed by Westrum was composed of

44	silica
20	alumina
20	barytes
16	water
100	

Klaproth found the same ingredients, and nearly in the same proportions †.

A variety of staurolite has been found only once, which has the following properties.

Its lustre is pearly, 2. Specific gravity 2.361. Colour brownish grey. With soda it melts into a purplish and yellowish frothy enamel. It is composed, according to Westrum, of

* Hauy, *Jour. de Min.* No. xxviii. 280.

† Beitrage, ii. 80.

47.5 silica
12.0 alumina
20.0 barytes
16.0 water
4.5 oxides of iron and manganese

100.0

GENUS XIII. SLA.

Sp. 1. Lazulite*.

This stone, which is found chiefly in the northern parts of Asia, was long known to mineralogists by the name of *lapus lazuli*.

Lazulite is always amorphous. Its texture is earthy. Its fracture uneven. Lustre 0. Opaque, or nearly so. Hardness 8 to 9. Specific gravity 2.76 to 2.945 †. Colour blue‡; often spotted white from specks of quartz, and yellow from particles of pyrites. Properties.

It retains its colour at 100° Wedgewood; in a higher heat it intumesces, and melts into a yellowish black mass. With acids it effervesces a little, and if previously calcined, forms with them a jelly.

Margraff published an analysis of lazulite in the Berlin Memoirs for 1758. His analysis has since been confirmed by Klaproth, who found a specimen of it to contain

* Kirwan, i. 283. † Hauy, iii. 145.—Brochant, i. 313. ‡ Brisson.

‡ Hence the name *lazulite*, from an Arabian word *azul*, which signifies *blue*.

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Composition.

46.0 silica
14.5 alumina
28.0 carbonat of lime
6.5 sulphat of lime
3.0 oxide of iron
2.0 water

100.0 *

From the experiments of Morveau, it appears that the colouring matter of lazulite is sulphuret of iron.

Genus XIV. Sal.

Sp. 1. Scapolite †.

This mineral has been found at Arendal in Norway. It is of a pearl white colour, and is crystallized in long four-sided rectangular prisms. Faces longitudinally streaked. Its specific gravity is 3.680, and it is hard enough to scratch glass. Lustre 2; glassy. Fracture foliated in two different directions. Transparency 1.62. Before the blow-pipe, froths and melts into a white enamel.

Composition.

According to Abelgaard, it is composed of

48 silica
30 alumina
14 lime
1 oxide of iron
2 water

95 ‡

* Beitrage, i. 196.
† Brochant, ii. 526.—Hauy, iii. 393.
‡ *Jour. de Phys.* lii. 33.

Class I. Gen. XIV. Sal.

Sp. 2. Dipyre *.

This mineral has been found at Mauleon in the Pyrenees, disseminated either in fascicular masses or in small prisms. Colour reddish or greyish white. Lustre 3, glassy. Hardness 8. Brittle. Specific gravity 2.630. Melts and froths before the blow-pipe. Phosphoresces slightly on hot coals. According to the analysis of Vauquelin, it is composed of

Composition.

60 silica
24 alumina
10 lime
2 water

96

Sp. 3. Hyalite †.

This stone is found frequently in trap rocks. It occurs in grains, filaments, and rhomboidal masses. Texture foliated. Fracture uneven, inclining to conchoidal. Lustre glassy ‡, 2 to 3. Transparency 2 to 3; sometimes, though seldom, it is opaque. Hardness 9. Specific gravity 2.11 §. Colour pure white. Infusible at 150° Wedgewood; but it yields to soda ||. According to Mr Link, it is composed of

Composition.

57 silica
18 alumina
15 lime

90 and a very little iron ¶

* Brochant, ii. 508.—Hauy iii. 242. † Kirwan, i. 296—Brochant, i. 272.

‡ Hence probably the name *hyalite*, which was imposed by Werner from ὑαλις *glass*, and λιθος *a stone*. § Kirwan. || Id.

¶ Crell's *Annals*, 1790, 2 Band. 232.

Book III. Chap. II.

Sp. 4. Zeolite *.

Mesotype of Hauy.

This stone was first described by Cronstedt in the Stockholm Transactions for 1756. It is found sometimes amorphous and sometimes crystallized. The primitive form of its crystalsi s a rectangular prism, whose bases are squares. The most common variety is a long four sided prism, terminated by low four-sided pyramids†.

Properties. Its texture is striated or fibrous. Its lustre is silky, from 3 to 1. Transparency from 2 to 4; sometimes 1. Refracts double. Hardness 6 to 8; sometimes only 4. Absorbs water. Specific gravity 2.0833. Colour white, often with a shade of red or yellow. When heated it becomes electric like the tourmaline‡. Before the blow-pipe it froths §, emits a phosphorescent light, and melts into a white semitransparent enamel, too soft to cut glass, and soluble in acids. In acids it dissolves slowly and partially without effervescence; and at last, unless the quantity of liquid be too great, it is converted into a jelly. A specimen of zeolite ‖, analysed by Vauquelin, contained

Composition.

53.00	silica
27.00	alumina
9.46	lime
10.00	water
99.46 ¶	

* Kirwan, i. 278.—Guettard, iv. 637.—Bucquet, *Mem. Sav. Etrang* ix. 576.—Pelletier, *Jour. de Phys.* xx. 420.—Hauy, iii. 151.—Brochant, i. 298. † Hauy, *Jour. de Min.* No. xiv. 86.

‡ Hauy, *Jour. de Min.* No. xxviii. 276.

§ Hence the name *zeolite* given to this mineral by Cronstedt; from ζεω *to ferment*, and λιθος *a stone*.

‖ Dr Black was accustomed to mention, in the course of his lectures, that Dr Hutton had discovered *soda* in zeolite. This discovery was verified by Dr Kennedy. He had finished the analysis of several varieties of zeolite.

¶ *Jour. de Min.* No. xliv. 576.

Class I. Gen. XIV. Sal.

Sp. 5. Stilbite *.

Lamellar zeolite of Werner.

This stone was first formed into a distinct species by Mr Hauy. Formerly it was considered as a variety of zeolite.

Crystals.

The primitive form of its crystals is a rectangular prism, whose bases are rectangles. It crystallizes sometimes in dodecahedrons, consisting of a four-sided prism with hexagonal faces, terminated by four-sided summits, whose faces are oblique parallelograms; sometimes in six-sided prisms, two of whose solid angles are wanting, and a small triangular face in their place †.

Properties.

Its texture is foliated. The laminæ are easily separated from each other, and are somewhat flexible. Lustre pearly, 2 or 3 ‡. Hardness inferior to that of zeolite, which scratches stilbite. Brittle. Specific gravity 2.500 §. Colour pearl white, or greasy. Powder bright white, sometimes with a shade of red. This powder, when exposed to the air, cakes and adheres as if it had absorbed water. It causes syrup of violets to assume a green colour. When stilbite is heated in a porcelain crucible, it swells up and assumes the colour and semitransparency of baked porcelain. By this process it loses 0.185 of its weight. Before the blow-pipe it froths like borax, and then melts into an opaque white coloured enamel ¶. Does not gelatinise in acids. Not electric by heat.

According to the analysis of Vauquelin, it is composed of

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* Hauy, iii. 161.—Brochant, i. 308.

† Hauy, *Jour de Min* No. xiv. 86.

‡ Hence the name given to this mineral by Hauy, *stilbite*, from στιλβω *to shine*.

§ Hauy, Ibid. No. xxviii. 276.

¶ Vauquelin, Ibid. No. xxxix. 161.

52.0 silica
17.5 alumina
9.0 lime
18.5 water

97.0 *

It occurs most commonly in lava; but found also in primitive rocks.

Sp. 6. Analcime †.

Cubic zeolite of Werner.

This stone, which was discovered by Mr Dolomieu, is found crystallized in the cavities of lava. It was first made a distinct species by Mr Hauy. Mineralogists had formerly confounded it with zeolite. It occurs in the rock of Dunbarton in Scotland.

Crystals. The primitive form of its crystals is a cube. It is sometimes found crystallized in cubes, whose solid angles are wanting, and three small triangular faces in place of each; sometimes in polyhedrons with 24 faces. It is usually somewhat transparent. Hardness about 9; scratches glass slightly. Specific gravity above 2. Colour white; sometimes red. When rubbed, it acquires only a small degree of electricity, and with difficulty ‡. Before the blow-pipe it melts without frothing into a white semitransparent glass §.

* Vauquelin, *Jour. de Min.* No. xxxix. 164.

† Hauy, iii. 180.—Brochant, i. 309.

‡ Hence the name *analcime* given it by Hauy, from αναλκις, *weak*.

§ Hauy, *Jour. de Min.* No. xiv. 86. and xxviii. 278.

Sp. 7. Chabasie*.

This mineral, which was first separated from the preceeding species by Bosc d'Antic and Hauy, is found at Oberstein in Germany. It is found usually in crystals. Crystals. The primitive form is a rhomboid differing very little from a cube, having the angle at its summit $93\frac{1}{2}°$. Sometimes it occurs in that form, at other times six of its edges are truncated, and the truncatures unite, 3 and 3, at the two opposite angles; while the other 6 angles are truncated: sometimes in double six-sided pyramids applied base to base, having the six angles at the base and the three acute edges of each pyramid truncated. Colour white; somewhat transparent. Specific gravity 2.7176. Scratches glass. Melts before the blow-pipe into a white spongy mass.

Sp. 8. Prehnite†.

Though this stone had been mentioned by Sage ‡, Romé de Lisle §, and other mineralogists, Werner was the first who properly distinguished it from other minerals, and made it a distinct species. The specimen History. which he examined was brought from the Cape of Good Hope by Colonel Prehn; hence the name *prehnite*, by which he distinguished it. It was found near Dunbarton by Mr Grotche ‖; and since that time it has been observed in other parts of Scotland.

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* Hauy, iii. 176.—Brochant, i. 309.

† Kirwan, i. 274.—Hassenfratz, *Jour. de Phys.* xxxii. 81.—Sage, Ibid. xxxiv. 446.—Klaproth, *Beob. der Berlin*, 2 Band. 211.; and *Ann. de Chim.* i. 201.—Hauy, iii. 167.—Brochant, i. 295.

‡ *Miner.* i. 232. § *Crystall.* ii. 275. ‖ *Ann. de Chim.* i. 213.

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It is both amorphous and crystallized. The crystals are in groups, and confused: they seem to be four-sided prisms with dihedral summits *. Sometimes they are irregular six-sided plates, and sometimes flat rhomboidal parallelopipeds.

Its texture is foliated. Fracture uneven. Internal lustre pearly, scarcely 2. Transparency 3 to 2. Hardness 9. Brittle. Specific gravity 2.6097 to 2.6969†. Colour apple green, or greenish grey. Before the blowpipe it froths more violently than zeolite, and melts into a brown enamel. A specimen of prehnite, analysed by Klaproth, was composed of

Composition.

43.83	silica
30.33	alumina
18.33	lime
5.66	oxide of iron
1.16	air and water
99.31‡	

Whereas Mr Hassenfratz found in another specimen

50.0	silica
20.4	alumina
23.3	lime
4.9	iron
.9	water
.5	magnesia
100.0§	

The mineral known by the name of *koupholite* is a variety of the prehnite.

* Hauy, *Jour. de Min.* No. xxviii. 277. † Hauy, Ibid.
‡ *Ann. de Chim.* i. 208. § Ibid. and *Jour. de Phys.* No. xxxii. 81.

Genus XV. Sali.

Sp. 1. Thummerstone*.

Yanolite of Lametherie—*Axinite* of Hauy—*Glastein* of Klaproth.

This stone was first described by Mr Schreber, who found it near Balme d'Auris in Dauphiné, and gave it the name of *shorl violé* †. It was afterwards found near Thum in Saxony, in consequence of which Werner called it *thummerstone*.

It is sometimes amorphous; but more commonly crystallized. The primitive form of its crystals is a rectangular prism, whose bases are parallelograms with angles of 101° 32′ and 78° 28′‡. The most usual variety is a flat rhomboidal parallelopiped, with two of its opposite edges wanting, and a small face in place of each §. The faces of the parallelopiped are generally streaked longitudinally. Crystals.

The texture of thummerstone is foliated. Its fracture conchoidal. Lustre 2. Glassy. Transparency, when crystallized, 3 to 4, when amorphous, 2 to 1. Causes simple refraction ‖. Hardness 10 to 9. Specific gravity 3.2956. Colour clove brown; sometimes inclining to red, green, grey, violet, or black. Before the blow-pipe it froths like zeolite, and melts into a hard black enamel. With borax it exhibits the same phe- Properties.

* Kirwan, i. 273.—Pelletier, *Jour. de Phys.* xxvi. 66.—Brochant, i. 236.—Hauy, iii. 22.

† Romé de Lisle, ii. 353.

‡ Hauy, *Jour. de Min.* No. xxviii. 264.

§ Rome de Lisle, Ibid.

‖ Hauy, Ibid.

Book III. Chap. II.

nomena, or even when the stone is simply heated at the end of a pincer*.

A specimen of thummerstone, analysed by Klaproth, contained . . . . . 52.7 silica

Composition.

25.6 alumina
9.4 lime
9.6 oxide of iron, with a trace of manganese

97·3†

A specimen, analysed by Vauquelin, contained

44 silica
18 alumina
19 lime
14 oxide of iron
4 oxide of manganese

99‡

Sp. 2. Thallite§.

Green shorl of Dauphiny of De Lisle‖—*Delphinite* of Saussure—*Glassy actinolite* of Kirwan—*Glassy strahlstein* of Werner—*Epidote* of Hauy.

This stone is found in the fissures of mountains; and hitherto only in Dauphiny and on Chamouni in the Alps.

Crystals.

It is sometimes amorphous, and sometimes crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rhombs with angles of 114° 37′ and 65° 23′ ¶. The most usual variety is an elon-

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* Vauquelin, *Jour. de Min.* No. xxiii. 1.
† Beitrage, ii. 126.
‡ Vauquelin, Ibid.
§ Brochant, i. 510.—Hauy, iii. 102.
‖ *Crystall.* ii. 401.
¶ Hauy, *Jour. de Min.* xxviii. 271.

gated four-sided prism (often flattened), terminated by four-sided incomplete pyramids; sometimes it occurs in regular six-sided prisms*. The crystals are often very slender. Class I. Genus XV. SALI.

Its texture appears fibrous. Lustre 2. Glassy. Transparency 2 to 3, sometimes 4; sometimes nearly opaque. Causes single refraction. Hardness 8 to 10. Brittle. Specific gravity 3.4529 to 3.46. Colour dark green†. Powder white or yellowish green, and feels dry. It does not become electric by heat. Before the blow-pipe froths and melts into a black slag. With borax melts into a green bead‡. Properties.

A specimen of thallite, analysed by Mr Descotils, contained . . . . . Composition.

37	silica
27	alumina
17	oxide of iron
14	lime
1.5	oxide of manganese
96.5§	

Sp. 3. Scorza.

This mineral is a green coloured sand, whose specific gravity is 3.35. It is found near Muska in Transylvania, near the river Arangos. Klaproth found it composed of

* Rome de Lisle, *Crystall.* ii. 401. and Hauy, *Jour. de Min.* No. xxx. 415.

† Hence the name *thallite*, given it by Lametherie, from θαλλος, *a green leaf.*

‡ Hauy and Descotils, *Jour. de Min.* No. xxx. 415.

§ Ibid. p. 420.

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43.00 silica
21.00 alumina
14.00 lime
16.50 oxide of iron
0.25 oxide of manganese

94.75 *

Sp 4. Garnet †.

This stone is found abundantly in many mountains. It is usually crystallized. The primitive form of its crystals is a dodecahedron whose sides are rhombs, with angles of 78° 31′ 44″, and 120° 28′ 16″. The inclination of the rhombs to each other is 120°. This dodecahedron may be considered as a four-sided prism, terminated by four-sided pyramids ‡. It is divisible into four parallelopipeds, whose sides are rhombs; and each of these may be divided into four tetrahedrons, whose sides are isosceles triangles, equal and similar to either of the halves into which the rhomboidal faces of the dodecahedron are divided by their shorter diagonal. The integrant molecules of garnet are similar tetrahedrons §. Sometimes the edges of the dodecahedron are wanting, and small faces in their place; and sometimes garnet is crystallized in polyhedrons, having 24 trapezoidal faces. For a description and figure of these, and

Crystals.

* Beitrage, iii. 282.

† Kirwan, i. 258.—Gerhard, *Disquisitio Physico-chymica Granatorum*, &c.—Pasumot, *Jour. de Phys.* iii. 442.—Wiegleb, *Ann. de Chim.* i. 231.—Brochant, i. 195.—Hauy, ii. 340.

‡ Rome de Lisle, ii. 322. and Hauy, *Ann. de Chim.* xvii. 305.

§ Hauy, Ibid. 306.

other varieties of garnet, the reader is referred to Romé de Lisle and Hauy *.

Properties.

The texture of garnet, as Bergman first shewed, is foliated †. Its fracture commonly conchoidal. Internal lustre from 4 to 3. Glassy and waxy. Transparency from 2 to 4; sometimes only 1 or 0. Causes single refraction ‡. Hardness from 10 to 14. Specific gravity 3.75 to 4.188. Colour usually red; often green. Brittle. Easily broke. Often attracted by the magnet. Fusible *per se* by the blow-pipe into a black glass.

Varieties.

Variety 1. Noble garnet§.—Internal lustre 3 to 4. Transparency 4 to 2. Hardness 13 to 14. Specific gravity 4 to 4.188. Colour deep red, inclining to violet ¶. Almost always in crystals.

Variety 2. Common garnet.—Found in mass, and disseminated; sometimes in crystals. Fracture uneven, inclining to the conchoidal. Internal lustre 2 to 3. Transparency from 3 to 0. Hardness 10 to 11; sometimes only 9. Specific gravity 3.75 to 4. Colour various; shades of green and brown; sometimes hyacinth red and brown red; rarely orange yellow.

A specimen of oriental garnet, analysed by Klaproth, contained

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* Hauy, *Ann. de Chim.* xvii. 306.

† *Opusc.* ii. 9.

‡ Hauy, *Jour de Min.* No. xxviii. 260.

§ This seems to be the *carbuncle* (ανθραξ) of Theophrastus, and the *carbunculus garamanticus* of other ancient writers.—See Hill's *Theophrastus*, περι λιθων, p. 74. and 77.

¶ Hence, according to many, the name *garnet* (in Latin *granatus*), from the resemblance of the stone in colour to the blossoms of the pomegranate.

Book III. Chap. II.

Composition.

35·75 silica
27.25 alumina
36.00 oxide of iron
0.25 oxide of manganese

99·25 *

A specimen of red garnet, analysed by Vauquelin, contained . . . . . 52.0 silica
20.0 alumina
17.0 oxide of iron
7.7 lime

96.7 †

And a specimen of black garnet,
43 silica
16 alumina
20 lime
16 oxide of iron
4 water and volatile matter

99

Sp. 5. Pyrop.

This mineral, which is found in Bohemia, and was formerly distinguished by the name of Bohemian garnet, has been lately separated from the garnet by Werner, and made a distinct species. It is never found crystallized, but only in round or angular fragments, usually small. Colour deep red ‡, which passes to orange

* Beitrage, ii. 26.

† *Jour. de Min.* No. xliv. 575.

‡ Hence the name πυρωψ.

when the mineral is exposed to the sun. Very hard. Specific gravity 3.718 to 3.941. Fracture conchoidal, and very brilliant*. Lustre glassy 4. Transparency 2. According to the analysis of Klaproth, it is composed of

Composition.

40.00	silica.
28.50	alumina
10.00	magnesia
3.50	lime
16.50	oxide of iron
0.25	oxide of manganese
98.75†	

Genus XVI. Sail.

The minerals belonging to this genus are rather mechanical mixtures than chemical compounds.

Sp. 1. Basalt.

Properties.

This mineral constitutes the base of many mountains. Its colour is greyish black. Occurs frequently in round blocks. In mountains it is often formed of prismatic masses more or less regular. Internal lustre 0. Sometimes interspersed with shining specks of hornblende. Texture earthy. Fracture uneven. Streak ash grey. Hardness 8 to 9. Difficult to break. Feel harsh. Sounds strongly under the hammer. Specific gravity 2.864 to 3.000. Before the blow-pipe it melts into a black glass attracted by the magnet. A specimen from Staffa, analysed by Dr Kennedy, contained the following constituents:

* *Jour. de Phys.* liii. 227. † Beitrage, ii. 21.

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Composition.

44 silica
16 alumina
16 oxide of iron
9 lime
5 water
4 soda
1 muriatic acid

99 *

A specimen from Hasenberg yielded to Klaproth,

44.50 silica
16.75 alumina
20.00 oxide of iron
9.50 lime
2.25 magnesia
0.12 oxide of manganese
2.60 soda
2.00 water

97.72 †

Sp. 2. Wacken.

This mineral occurs in mass; sometimes it forms strata, but more frequently it runs in veins. Colour dark greenish grey, which often passes to mountain green or blackish green. Lustre 0. Fracture even. Texture earthy. Opaque. Soft. Easily broken. Feels slightly greasy. Specific gravity from 2.535 to 2.893. Easily melts before the blow-pipe. Liable to spontaneous decomposition.

* *Edin. Trans.* v. 89.

† Beitrage, iii. 253.—He found also traces of muriatic acid.

Sp. 3. Klingstein*.

This mineral composes whole mountains. They are usually insulated; and, like basalt, shew a tendency to assume the form of four-sided prisms. Its colour is usually deep grey, of various shades; but most commonly greenish. Sometimes various shades appear together, which gives it the appearance of being spotted. Found not only constituting mountains, but also in globular masses, &c. Internal lustre 2; chiefly from some crystals of hornblende and felspar which it contains. Structure slaty. Texture compact. Fracture usually splintery; sometimes conchoidal. Usually opaque; sometimes transparency 1. Hardness 7 to 9. Brittle. Gives a clear sound when struck with a hammer. Specific gravity 2.575. Powder light grey. Melts easily into a glass. A specimen analysed by Klaproth yielded

Properties.

57.25	silica
23.50	alumina
2.75	lime
3.25	oxide of iron
0.25	oxide of manganese
8.10	soda
3.00	water
98.10	

Composition.

Sp. 4. Keiselschiefer†.

This mineral occurs usually in blocks and amorphous

* Brochant, i. 437.—Klaproth, iii. 229.

† Kirwan, i. 305.—Brochant, i. 282.

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masses of different sizes; very often in the beds of rivers. Colour various shades of grey. Structure slaty. Usually opaque; transparency sometimes 1. Hardness 9 to 10. Brittle. Specific gravity from 2.880 to 2.415. Infusible *per se*. This species is divided into two subspecies.

Subspecies 1. Common keiselschiefer.

Subspecies.

Colour blackish grey or greenish. Often traversed by veins of quartz. Surface smooth. Lustre internal 0. Texture compact. Fracture splintery, or imperfectly conchoidal. Composed, according to Wiegleb, of

75.00 silica
10.00 lime
4.58 magnesia
3.54 iron
5.02 inflammable matter

98.14*

Subspecies 2. Lydian stone.

Commonly intersected by veins of quartz. Fracture even; sometimes inclining to conchoidal. Lustre scarce 1. Hardness 10. Specific gravity 2.596. Powder black. Colour greyish black.

This, or a stone similar to it, was used by the ancients as a touchstone. They drew the metal to be examined along the stone, and judged of its purity by the colour of the metallic streak. On this account they called it βασανος, "the trier." They called it also *Lydian stone;* because, as Theophrastus informs us, it was found most abundantly in the river Tmolus in Lydia†.

* Crell's *Annals*, 1788, ii. 140. † Hill's *Theophrastus*, περι λιθων, p. 190.

Genus XVII. Ams.

Sp. 1. Cyanite *.

Sappare of Saussure—*Disthene* of Hauy.

This stone was first described by Mr Saussure the son, who gave it the name of *sappare*†. It is commonly found in granite rocks. The primitive form of its crystals is a four-sided oblique prism, whose sides are inclined at an angle of 103°. The base forms with one side of the prism an angle of 103°; with another, an angle of 77°. It is sometimes crystallized in six-sided prisms ‡.

Its texture is foliated. Fracture radiated, rays curved, and interlaced. Fragments long, splintery. Lustre pearly, 2 to 3. Transparency of the laminæ 3. Causes single refraction §. Hardness 6 to 8. Brittle. Specific gravity from 3.517 to 3.622 ‖. Feels somewhat greasy. Colour milk white, with shades of sky or prussian blue ¶; sometimes bluish grey; sometimes partly bluish grey, partly yellowish or greenish grey. Properties.

Before the blow-pipe it becomes almost perfectly white, but does not melt. According to the analysis of Saussure, it is composed of

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* Kirwan, i. 209.—Sage, *Jour. de Phys.* xxxv. 39.—Hauy, iii. 220.—Brochant, i. 501.

† *Jour. de Phys.* xxxiv. 213.

‡ Hauy, *Jour. de Min.* No. xxviii. 282.

§ Hauy, Ibid. ‖ Kirwan.

¶ Hence the name *cyanite*, imposed by Werner.

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Composition.

66.92 alumina
13.25 magnesia
12.81 silica
5.48 iron
1.71 lime

100.17 *

Cyanite has also been analysed by Struvius and Hermann, who agree with Saussure as to the ingredients; but differ widely from him and one another as to the proportions.

Struvius.		Hermann.
5.5	. . . . .	30 alumina
30.5	. . . . .	39 magnesia
51.5	. . . . .	23 silica
5.0	. . . . .	2 iron
4.0	. . . . .	3 lime
96.5 †		97 ‡

Genus XVIII. Mea.

Sp. 1. Serpentine ||.

Properties.

This stone is found in amorphous masses, forming strata, and even entire mountains. Its fracture is splintery, sometimes inclining to conchoidal. Lustre 0, or 1. Opaque. Transparency sometimes 1. Hardness 6 to 7. Specific gravity 2.574 to 2.709. Feels rather soft, almost greasy. Generally emits an earthy smell when breathed

* *Jour. de Phys.* xxxiv. 213. † Crell's *Annals*, 1790. ‡ Ibid.
|| Kirwan, i. 156.—Margraff, *Mem. Berlin*, 1759, p. 3.—Bayen, *Jour. de Phys.* xiii. 46.—Mayer, Crell's *Annals*, 1789, ii. 416.—Brochant, i. 481.

upon. Its colours are various shades of green, yellow, red, grey, brown, blue: commonly one or two colours form the ground, and one or more appear in spots or veins *. Class I. Gen. XVIII. Msa.

Before the blow-pipe it hardens and does not melt.

A specimen of serpentine, analysed by Mr Chenevix, contained Composition.

34.5	magnesia
28.0	silica
23.0	alumina
4.5	oxide of iron
0.5	lime
10.5	water
101.0 †	

Sp. 2. Nephrite ‡.

Jade.

This stone was formerly called *lapis niphriticus*, and was much celebrated for its medical virtues. It is found in Egypt, China, America, and in the Siberian and Hungarian mountains. It is sometimes adhering to rocks, and sometimes in detached round pieces.

Its surface is smooth. Its fracture splintery. External lustre 0, or scarce 1; internal waxy, 1. Trans- Properties.

* Hence the name *serpentine* given to this stone, from a supposed resemblance in colours to the skin of a serpent.

† *Ann. de Chim.* xxviii. 199.

‡ Kirwan, i. 171.—Bartolin, *De Lapide Nephritico.*—Lehmann, *Nov. Comm. Petropol.* x. 381.—Hœpfner, *Hist. Nat. de la Suisse*, i. 251.—Brochant, i. 467.

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parency from 2 to 1. Hardness 10. Not brittle. Specific gravity from 2.97 to 3.380; or, according to Saussure, to 3.389. Feels greasy. Looks as if it had imbibed oil. Colour dark leek green, or verging towards blue; in some prominencies inclining to greenish or bluish white. When heated it becomes more transparent and brittle, and is infusible *per se* into a white semitransparent glass. According to Hœpfner, it is composed of

Composition.

47	silica
38	carbonat of magnesia
9	iron
4	alumina
2	carbonat of lime
100	

This is the stone which the inhabitants of New Zealand make into hatchets and other cutting instruments. The variety which they use is called *bieldstein* by Werner.

Genus XIX. Msai.

Sp. 1. Potstone *.

Properties.

This stone is found in nests and beds, and is always amorphous. Its structure is often slaty. Fracture undulatingly foliated. Lustre from 1 to 3. Greasy. Transparency from 0 to 1. Hardness 4 to 6. Brittle. Specific gravity from 2.8531 to 3.023. Feels greasy. Sometimes absorbs water. Colour grey with a shade

* Kirwan, i. 155.—Brochant, i. 405.

of green, and sometimes of red or yellow; sometimes leek green; sometimes speckled with red.

Potstone is not much affected by fire; and has therefore been made into utensils for boiling water; hence its name.

Composition.

According to Wiegleb, the potstone of Como contains

38	magnesia
38	silica
7	alumina
5	iron
1	carbonat of lime
1	fluoric acid
90	

Sp. 2. Chlorite *.

This mineral enters as an ingredient into different mountains. It is sometimes amorphous, and sometimes crystallized in oblong, four-sided, accuminated crystals.

Its texture is foliated. Its lustre from 0 to 2. Opaque. Hardness from 4 to 6; sometimes in loose scales. Colour green.

Subspecies 1. Earthy chlorite.

Subspecies.

Composed of scales scarcely cohering, either heaped together, or investing other stones. Feels greasy. Gives an earthy smell when breathed on. Difficult to pulverise. Colour grass green; sometimes greenish brown; sometimes dark green, inclining to black. Streak white. When the powder of chlorite is exposed to the blow-pipe it

* Kirwan, i. 137.—Brochant, i. 408.

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becomes brown. Before the blow pipe, it froths and melts into a dark brown glass; with borax it forms a greenish brown glass *.

Subspecies 2. Common chlorite.

Texture earthy. Lustre 1. Hardness 6. Feel meagre. Colour dark green. Streak mountain green.

Subspecies 3. Foliated chlorite.

Colour dark green; sometimes crystallized in six-sided tables. Lustre 2 to 3. Greasy or pearly. Texture foliated. Transparency 1.

Subspecies 4. Shistose chlorite.

Structure slaty. Fragments flatted. Internal lustre 1 to 2. Hardness 5. Colour greenish grey, or dark green inclining to black. Streak mountain green.

Composition.

A specimen of the first variety, analysed by Vauquelin, contained . . . . 43.3 oxide of iron
26.0 silica
15.5 alumina
8.0 magnesia
2.0 muriat of potass
4.0 water

98.8 †

A specimen of the same variety yielded Mr Hæpner

* Vauquelin, *Jour. de Min.* No xxxix. 167.
† *Ann. de Chim.* xxx. 106.

12.92 oxide of iron
37.50 silica
4.17 alumina
43.75 magnesia
1.66 lime

100.00 *

A specimen of the second variety, analysed by the same chemist, contained

19.15 oxide of iron
41.15 silica
6.13 alumina
39.47 magnesia
1.50 lime
1.50 air and water

99.90 †

On the supposition that these analyses are accurate, the enormous difference between them is a demonstration that chlorite is not a chemical combination, but a mechanical mixture.

Sp. 3. Lithomarga ‡.

This mineral occurs in nests in many mountains, especially in those composed of basalt. Texture earthy. Fracture conchoidal. Lustre 0 to 2. Opaque. Hardness 3 to 7. Specific gravity, when pretty hard, 2.815. Surface smooth, and feels soapy. Adheres strongly to the tongue. Falls to pieces, and then to powder, Properties.

* Saussure's *Voyages*, ii. 133.
† Crell's *Annals*, 1760, p. 56.
‡ Kirwan, i. 187.—Brochant, i. 447.

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in water; but does not diffuse itself through that liquid. Infusible *per se* before the blow-pipe.

Varieties.

Variety 1. Friable lithomarga.—Formed of scaly particles slightly cohering. Lustre 1 to 0. Hardness 3 to 4. Exceedingly light. Feels very smooth, and assumes a polish from the nail. Colour white; sometimes tinged yellow or red.

Variety 2. Indurated lithomarga.—Hardness 4 to 7. The softer sort adheres very strongly to the tongue when newly broken; the harder very moderately. Colours grey, yellow, red, brown, blue.

Genus XX. Saim.

Sp. 1. Melanite*.

This species has been only lately introduced by Werner, and has not yet been precisely described.

The melanite is found in the neighbourhood of Vesuvius, and was called before black *garnet*. Its colour is black or brownish black. Crystallized in six-sided prisms terminated by trihedral summits. By the analysis of Klaproth, it is composed of

Composition.

40.0	silica
28.5	alumina
16.5	oxide of iron
10.0	magnesia
3.5	lime
0.25	oxide of manganese
98.75	

* Brochant, i. 191.

Genus XXI. Samli.

Sp. 1. Slate.

Thonschiefer of Werner—*Argillite* of Kirwan—*Argillaceous Shistus.*

This stone constitutes a part of many mountains.

Its structure is slaty. Its texture foliated. Fracture splintery. Fragments often tabular. Lustre most commonly silky, 2; sometimes 0. Transparency from 0 to 1. Hardness from 5 to 8. Specific gravity from 2.67 to 2.88. Does not adhere to the tongue. Gives a clear sound when struck Streak white or grey. Colour most commonly grey, with a shade of blue, green, or black; sometimes purplish, yellowish, mountain green, brown, bluish black; sometimes striped or spotted with a darker colour than the ground. Properties.

It is composed, according to Kirwan, of silica, alumina, magnesia, lime, oxide of iron. In some varieties the lime is wanting. Several varieties contain a considerable quantity of carbonaceous matter.

Sp. 2. Bole †.

This mineral occurs chiefly in the isle of Lemnos, at Sienna in Italy, and in Silesia.

Its texture earthy. Fracture conchoidal. Lustre 0. Transparency scarce 1. Hardness 4. Specific gravity from 1.4 to 2. Acquires a polish by friction. Adheres to the tongue. Feels greasy. Colour yellow or brown; sometimes red; sometimes spotted. Properties.

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* Kirwan, i. 234.

† Kirwan, i. 191.—Brochant, i. 459.

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The Lemnian earth which belongs to this species, according to the analysis of Bergman, contains

47.0 silica
19.0 alumina
6.0 carbonat of magnesia
5.4 carbonat of lime
5.4 oxide of iron
17.0 water and air
99.8*

Genus XXII. Slacmi.

Sp. 1. Smaragdite†.

Diallage of Hauy—*Resplendent Hornblende.*

This stone was called *smaragdite* by Mr Saussure, from some resemblance which it has to the emerald. Never crystallized. Its texture is foliated. Easily divided into plates. The laminæ are inflexible. Fracture even. Hardness 7. Specific gravity 3. Colour in some cases fine green; in others it has the grey colour and metallic lustre of mica: it assumes all the shades of colour between these two extremes‡.

Composition.

According to the analysis of Vauquelin, it is composed of . . . . . 50.0 silica
13.0 lime
11.0 alumina
7.5 oxide of chromium
6.0 magnesia
5.5 oxide of iron
1.5 oxide of copper
94.5§

* *Opusc.* iv. 157. † Brochant, ii. 506.—Hauy, iii. 125.
‡ Hauy, *Jour. de Min.* No. xxviii. 272. § *Ann. de Chim.* xxx. 106.

Class I. Gen. XXIII. Sm.

Genus XXIII. Sm.

Sp. 1. Kiffekil *.

Meerschaum—Seafroth.

This mineral is dug up near Konie in Natolia, and is employed in forming the bowls of Turkish tobacco pipes. The sale of it supports a monastery of dervises established near the place where it is dug. It is found in a large fissure six feet wide, in grey calcareous earth. The workmen assert that it grows again in the fissure †, and puffs itself up like froth ‡. This mineral, when fresh dug, is of the consistence of wax; it feels soft and greasy; its colour is yellow; its specific gravity 1.600 §: when thrown on the fire it sweats, emits a fetid vapour, becomes hard, and perfectly white. Properties.

According to the analysis of Klaproth, it is composed of . . . . . Composition.

50.50	silica
17.25	magnesia
25.00	water
5.00	carbonic acid
.50	lime
98.25 ‖	

Sp. 2. Steatites ¶.

Though this mineral was noticed by the ancients,

* Kirwan's *Min.* i. 144.—Brochant, i. 462.

† Reignegg, *Philos. Mag.* iii. 165.

‡ Hence the name *kiff-kil*, or rather *keff-kelli*, "clay-froth," or "light clay."

§ Klaproth. ‖ Beitrage, ii. 172.

¶ Kirwan, i. 151.—Pott, *Mem. Berlin*, 1747, p. 57.—Wiegleb, *Jour.*

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little attention was paid to it by mineralogists, till Mr Pott published his experiments on it in the Berlin Memoirs for 1747.

Properties.

It is usually amorphous, but sometimes it is crystallized in six-sided prisms. Its texture is commonly earthy, but sometimes foliated. Lustre from 0 to 2. Transparency from 0 to 2. Hardness 4 to 7. Specific gravity from 2 61 to 2.794*. Feels greasy. Seldom adheres to the tongue. Colour usually white or grey; often with a tint of other colours; the foliated commonly green. Does not melt *per se* before the blow-pipe.

Varieties.

Variety 1. Semi-indurated steatites. Texture earthy. Fracture sometimes coarse splintery. Lustre 0. Transparency 0, or scarce 1. Hardness 4 to 5. Absorbs water. Takes a polish from the nail. Colour white, with a shade of grey, yellow, or green; sometimes pure white; sometimes it contains dendritical figures; and sometimes red veins.

Variety 2. Indurated steatites.—Fracture fine splintery, often mixed with imperfectly conchoidal. External lustre 2 to 1, internal 0. Transparency 2. Often has the feel of soap. Absorbs water. Colour yellowish or greenish grey; often veined or spotted with deep yellow or red.

Variety 3. Foliated or striated steatites.—The texture of this variety is usually foliated; sometimes striated. Fragments cubiform. Lustre 3. Transparency 2 to 1. Hardness 6 to 7. Colour leek green, pas-

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de Phys. xxix. 60.—Lavoisier, *Mem. Par.* 1778, p. 433.—Brochant, i. 474

* Brisson.

sing into mountain green or sulphur yellow. Streak pale greenish grey. When heated to redness, it becomes grey; and at 147° Wedgewood, it forms a grey porous porcelain mass*. Class I. Gen. XXIV. Msi.

A specimen of steatites analysed by Klaproth, contained . . . . . 59.5 silica
30.5 magnesia
2.5 iron
5.5 water
98.0† Composition.

A specimen of white steatites, analysed by Mr Chenevix, contained 60.00 silica
28.50 magnesia
3.00 alumina
2.50 lime
2.25 iron
96.25‡

Genus XXIV. Msi.

Sp. 1. Chrysolite§.

Peridot of the French—*Topaz* of the ancients.

The name *chrysolite* was applied, without discrimination, to a great variety of stones, till Werner defined it accurately, and confined it to that stone which the

* Kirwan, i. 155. † Beitrage, ii. 179.

‡ *Ann. de Chim.* xxviii. 200.

§ Kirwan, i 262.—Carthcuser, *Min.* 94.—Dolomieu, *Jour. de Min.* No. xxix. 365.—La Metherie, *Nouv. Jour. de Phys.* i. 397.—Brochant, i. 170.—Hauy, iii. 198.

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French chemists distinguish by the appellation of *peridot*. This stone is the *topaz* of the ancients; their chrysolite is now called *topaz**.

Crystals.

Chrysolite is found in angular fragments, in grains, and crystallized. The primitive form of its crystals is a right-angled parallelopiped, whose length, breadth, and thickness, are as 5, $\sqrt{8}$, $\sqrt{5}$†. The edges of the prism are usually truncated.

Properties.

The texture of the chrysolite is foliated. Its fracture conchoidal. Its internal lustre from 2 to 4. Its transparency from 4 to 2. Causes double refraction. Hardness 9 to 10. Brittle. Specific gravity from 3.265 to 3.45. Colour green. It is infusible at 150°, but loses its transparency, and becomes blackish grey‡. With borax it melts without effervescence into a transparent glass of a light green colour. Infusible with microcosmic salt§ and fixed alkali‖.

Varieties.

Variety 1. Common chrysolite.—Found in Ceylon, South America, and in Bohemia, amidst sand and gravel¶. Lustre 3 to 4. Transparency 4 to 3. Colour yellowish green, sometimes verging to olive green, sometimes to pale yellow.

Variety 2. Olive chrysolite. *Olivine* **.—Found commonly in basalt; sometimes in small grains, sometimes in pretty large pieces: but it has not been observed in crystals††. Lustre 2 to 3. Transparency 3 to 2. Colour olive green.

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* Plinii Lib. xxxvii. c. 8.

† Hauy, *Jour. de Min.* No. xxviii. 281.

‡ Kirwan's *Min.* i. 263.

§ Vauquelin, *Ann. de Chim.* xxi. 97.

‖ Kirwan, i. 263.

¶ Coquebert, *Jour. de Min.* No. xxii. 20.

** Kirwan, i. 263.—Le Lievre, *Jour. de Phys.* xxx. 397.—Brochant, i. 175.

†† Emmerling affirms that it is found only in basalt, properly so call-

Class I. Gen. XXV. Sml. Composition.

The first variety, according to the analysis of Klaproth, is composed of

41.5 magnesia
38.5 silica
19.0 oxide of iron

99.0*

According to that of Vauquelin, it is composed of

51.5 magnesia
38.0 silica
9.5 oxide of iron

99.0†

The second variety, according to the analysis of Klaproth, is composed of

37.58 magnesia
50.00 silica
11.75 oxide of iron
.21 lime

99.54‡

Genus XXV. Sml.

Sp. 1. Asbestus§.

This mineral was well known to the ancients. They

ed, and never in the other rocks of the trap formation; but it has been found in Arthur's Seat, though that rock is not a basalt properly so called.

* Klaproth's *Beitrage*, i. 103. † *Ann. de Chim.* xxi. 97.

‡ *Beitrage*, i. 112.

§ Kirwan, i. 159.—Bergman, iv. 160.—Plot, *Phil. Trans.* xv. 1051.—Nebel, *Jour. de Phys.* ii. 62.—Ibid. iii. 367.—Hauy, iii. 245.—Brochant, i. 492.

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even made a kind of cloth from one of the varieties, which was famous among them for its incombustibility. It is found abundantly in most mountainous countries, and nowhere more abundantly than in Scotland.

Properties.

It is found in amorphous masses. Its texture is fibrous. Its fragments often long splintery. Lustre from 0 to 2; sometimes 3, and then it is metallic. Transparency from 0 to 2. Hardness from 3 to 7. Specific gravity from 2.995 to 0.6806. Absorbs water. Colour usually white or green. Fusible *per se* by the blowpipe.

Subspecies 1. Common asbestus.

Subspecies.

Lustre 2 to 1, silky. Transparency 1. Hardness 6 to 7. Specific gravity 2.547 to 2.995. Feels somewhat greasy. Colour leek green; sometimes olive or mountain green; sometimes greenish or yellowish grey. Streak grey. Powder grey.

Subspecies 2. Flexible asbestus.—*Amianthus.*

Composed of a bundle of threads slightly cohering. Fibres flexible. Lustre 1 to 2, sometimes 3. Transparency 1 to 2, sometimes 0. Hardness 3 to 4. Specific gravity, before it absorbs water, from 0.9088 to 2.3134; after absorbing water, from 1.5662 to 2.3803*. Feels greasy. Colour greyish or greenish white; sometimes yellowish or silvery white, olive or mountain green.

Subspecies 3. Elastic asbestus.—*Mountain cork.*

This variety has a strong resemblance to common cork. Its fibres are interwoven. Lustre commonly 0. Opaque. Hardness 4. Specific gravity, before ab-

* Brisson.

sorbing water, from 0.6806 to 0.9933; after absorbing water, from 1.2492 to 1.3492. Feels meagre. Yields to the fingers like cork, and is somewhat elastic. Colour white; sometimes with a shade of red or yellow; sometimes yellow or brown. Class I. Gen. XXV. Sml.

Subspecies 4. Ligniform asbestus.

Colour wood brown, which passes into yellow. Opaque. Very soft. Somewhat flexible, but not elastic. Adheres to the tongue. Feels harsh.

A specimen of the first subspecies from Dalecarlia, analysed by Bergman, contained Composition.

63.9 silica
16.0 carbonat of magnesia
12.8 carbonat of lime
6.0 oxide of iron
1.1 alumina

99.8*

A specimen of the second subspecies yielded to the same chemist

64.0 silica
17.2 carbonat of magnesia
13.9 carbonat of lime
2.7 alumina
2.2 oxide of iron

100.0†

A specimen of the third subspecies contained, according to the same analysis,

* *Opusc.* iv. 170. † Ibid. p. 163

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56.2 silica
26.1 carbonat of magnesia
12.7 carbonat of lime
3.0 iron
2.0 alumina

100.0 *

Twelve different specimens of asbestus, analysed by Bergman, yielded the same ingredients, differing a little in their proportions †.

Sp. 2. Actinote ‡.

Strahlstein of Werner, except the *glassy*; *Rayonante* of Saussure and Brochant. *Actinolite*, *Asbestinite*, *Asbestoid* of Kirwan. *Actinote* of Hauy.

Properties.

This mineral occurs in the primitive rocks, and is usually mixed with those stones which contain a notable portion of magnesia. It is found both massive and crystallized. The primitive form of its crystals, according to Hauy, is a four-sided prism whose bases are rhombs, and which he presumes to be the same with the primitive form of hornblende. It occurs in six-sided prisms, in needles, and in small plates. Colour most commonly greenish. Texture radiated rays diverging from a centre. Fragments undeterminate. Transparency 1; often opaque. Difficult to break. Specific gravity 2.916 to 3.31. Fusible before the blow-pipe. It is divided into two subspecies.

* *Opusc.* iv. 170. † Ibid. p. 175.
‡ Brochant, i. 504.—Hauy, iii. 73.

Class I. Gen. XXV. Sml.

Subspecies 1. Asbestiform Actinote.

Colour white or greenish, reddish, or yellowish grey; also olive and mountain green. Seldom crystallized. Lustre 0, 1, 2. Pearly. Usually opaque. Scratch, greenish white. Soft. Specific gravity 2.916.

Subspecies 2. Common Actinote.

Colour usually green; sometimes reddish or yellowish white, and sometimes brown. Lustre 2, 3. Glassy. Transparency 1 to 2. Feel slightly greasy.

Composition.

A specimen of the first variety, analysed by Bergman, yielded

64.0 silica
20.0 magnesia
2.7 alumina
9.3 lime
4.0 iron

100.0 *

Sp. 3. Malacolite †.

Sahlite of Dandrada.

Properties.

This mineral was first observed in Sweden in the silver mine of Sahla in Westermania; afterwards in Norway. Colour green. Found massive and crystallized in six-sided prisms, having two opposite edges truncated. Lustre 1. Waxy. Texture lamellated. Transparency 1. Hardness 9. Feel soft. Specific gravity 3.2307. Melts before the blow-pipe into a porous glass. According to the analysis of Vauquelin, it is composed of

* *Opusc.* iv. 172.

† Hauy, iv. 379.—Brochant, ii. 518.

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53 silica
20 lime
19 magnesia
3 alumina
4 oxides of iron and manganese

99

Hauy has shewn that it bears a striking resemblance to Augite.

Genus XXVI. Silm.

Sp. 1. Augite*.

Pyroxene of Hauy.—*Volcanite* of Delametherie.— *Octahedral Basaltine* of Kirwan.

This mineral is found in basalt and lava. It is sometimes in grains, but most commonly in crystals. The primitive form of its crystals is an oblique angled prism, whose bases are rhombs with angles of 92° 18′ and 37° 42′ †. It generally crystallizes in six or eight-sided prisms, terminated by dihedral summits ‡. Its texture is foliated. Lustre greasy 3. Hardness 9. Fracture imperfectly conchoidal and brilliant. Usually somewhat transparent at the edges. Colour deep green, or greenish black. Powder greenish grey. Specific gravity from 3.182 to 3.47. Scratches glass. Commonly attracted by the magnet §. Scarcely fusible by the blow-pipe ‖.

Properties.

* Kirwan, i. 219.—Brochant, i. 179.—Hauy, iii. 80.
† Hauy, *Jour. de Min.* xxviii. 269. ‡ De Lisle, ii. 398.
§ Ferber. ‖ Le Lievre.

With borax it melts into a yellowish glass, which appears red while it is hot *. Class I. Gen. XXVII. SMIL.

According to the analysis of Vauquelin, it is composed of

Composition.

52.00	silica
14.66	oxide of iron
13.20	lime
10.00	magnesia
3.33	alumina
2.00	oxide of manganese
95.19 †	

GENUS XXVII. SMIL.

Sp. 1. Vesuvian ‡.

Hyacinthine of Delametherie—*Sorlo piceo* of Giœni—*Idocrase* of Hauy.

This mineral is found in lava, especially at Vesuvius, and was formerly confounded with the hyacinth. Its colour is brown or greenish; it is found in masses, but usually crystallized in rectangular eight-sided prisms, or rather four-sided prisms with their edges truncated. The primitive form of its crystals is the cube. Specific gravity from 3.39 to 3.409. Scratches glass. Internal lustre 2, greasy; external 4, glassy. Fracture imperfectly conchoidal. Transparency 2.1. Causes double refraction. Before the blow-pipe it melts into a

Properties.

* Vauquelin. † *Jour. de Min.* xxxix. 172.
‡ Brochant, i. 184.—Hauy, ii. 574. § *Opusc.* iv. 171.

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yellowish glass. it is composed of

According to the analysis of Stucke,

26.5 silica
40.2 magnesia
16.2 oxide of iron
16.0 lime

98.9 *

But according to Klaproth, two different specimens contained the following ingredients :

From Vesuvius.		From Siberia.
35·50		42.00 silica
33.00		34.00 lime
22.25		16.25 alumina
7·50		5·50 oxide of iron
0.25		oxide of manganese
98.50		97·75 †

This analysis would place the vesuvian in the fifteenth genus. A proof of the imperfection of our analytical methods.

Sp. 2. Meionite‡.

This mineral has hitherto been found only among the lava of Vesuvius near Mount Somma. Always crystallized. Primitive form a prism whose bases are squares. It occurs usually in eight-sided prisms, and terminated by four-sided pyramids. Sometimes the edges of the prism are truncated. Colour greyish white. Lustre 3,

* *Jour. de Phys.* xlvi. 69. † Beitrage, ii. 32. and 38.
‡ Hauy, ii. 586.—Brochant, ii. 519.

glassy. Texture foliated. Fracture flat, conchoidal. Transparency 2. Hardness 9. Scratches glass. Melts before the blow-pipe into a white spongy glass. Class I. Gen. XXVIII. Sl.

Genus XXVIII. Sl.

Sp. 1. Tremolite *.

Grammatite of Hauy.

This mineral is found chiefly near St Gothard in Switzerland; and takes its name from Mount Tremola, where it was first observed by Saussure. It occurs massive and in crystals. The primitive form of its crystals is a rhomboidal prism, whose sides are inclined to each other at angles of 126° 52′ 12″ and 53° 7′ 48″. It usually occurs in four-sided prisms, terminated by dihedral summits; and not unfrequently the two acute edges, or all the four, are truncated. Texture radiated. Fragments splintery. Specific gravity from 2.9 to 3.2. Fibres easily separated, so that it appears soft, yet it scratches glass. Phosphoresces very readily when struck or rubbed in the dark. Before the blow-pipe melts into a white scoria. Werner divides this species into three subspecies. Crystals.

Subspecies 1. Asbestiform tremolite.

Colour yellowish white; sometimes reddish, greenish, greyish. Always amorphous. Lustre 2, silky. Opaque or transparency 1. Soft. Easily broken. Subspecies.

Subspecies 2. Common tremolite.

Colour greenish white; sometimes greyish, reddish, yellowish. Found amorphous and in crystals. Crystals

* Brochant, i. 514.—Hauy, iii. 227

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longitudinally striated; external lustre 4; internally 3, 2; pearly. Transparency 1 to 3.

Subspecies 3. Glassy tremolite.

Colour greyish or yellowish white; sometimes greenish or reddish. Lustre 3, 4. Glassy. Transparency 2. Feels harsh.

Composition.

A specimen of tremolite, analysed by Klaproth, contained . . . . . 65.0 silica
38.0 lime
0.5 magnesia
0.5 oxide of iron
6.0 water and carbonic acid

100.0*

A specimen of this mineral from the Castlehill of Edinburgh, analysed by Dr Kennedy, yielded

51.5 silica
32.0 lime
0.5 alumina
0.5 oxide of iron
8.5 soda
5.0 carbonic acid

98.0 with some traces of magnesia and muriatic acid†.

Bournon has shewn that the property which the tremolite has of phosphorescing when rubbed, is owing to the presence of carbonat of lime. This carbonat may

* Crell's *Annals*, 1790, i. 54.

† *Trans. Edin.* vol. v. and *Phil. Mag.* xiv. 315

be separated by acids; and in that case the property vanishes*.

Class I. Gen. XXIX. Slk.

Genus XXIX. Slk.

This genus comprehends under it the only stony mineral known which contains the oxide of copper. Perhaps the metal is merely mechanically interposed. In that case this genus would be confounded with the last.

Sp. 1. Dioptase†.

This mineral is found in Siberia in a copper mine. Its colour is emerald green. It is crystallized in six-sided prisms, terminated by three-sided pyramids. Lustre 3, glassy. Texture foliated. Clivage triple. Transparency 2 to 3. Hardness 8. Specific gravity 3.3. Before the blow-pipe it is infusible; but becomes brown, and tinges the flame green. When melted with borax it gives a button of copper. According to the analysis of Vauquelin by the blow-pipe, it is composed of

Composition.

28.57	silica
28.57	oxide of copper
43.85	carbonat of lime
99.99	

Genus XXX. Ysi.

Sp. 1. Gadolinite‡.

This mineral was first observed by Captain Arhenius

* *Jour. de Min.* No. xiii. 1. † Hauy, iii. 136.—Brochart, ii. 511.
‡ Hauy, iii. 141.—Brochant, ii. 512.—Klaproth, iii. 52.

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lodged in a white felspar in the quarry of Ytterby in Sweden, and received the name *Gadolinite*, because Gadolin was the chemist who first ascertained its composition.

Properties.

Colour perfect black, passing sometimes to brown. Found in mass. Lustre 3, glassy. Fracture conchoidal. Hardness 10. Scratches quartz. Brittle. Specific gravity 4.0497. Gelatinizes with hot diluted nitric acid. Before the blow-pipe decrepitates, and assumes a whitish red colour, but does not melt. With borax it melts into a topaz-yellow glass. Affects the magnetic needle.

Composition.

According to the analysis of Vauquelin, it is composed of

35.0 yttria
25.5 silica
25.0 oxide of iron
2.0 lime
2.0 oxide of manganese
10.5 water and carbonic acid

100.0*

Klaproth, on the other hand, found

59.75 yttria
21.25 silica
18.00 oxide of iron
0.50 alumina

99.50†

This last analysis does not differ much from that which Ekeberg had before published.

* *Ann. de Chim.* xxxvi. 152.
† Ibid. xxxvii. 87.

Order II. SALINE STONES.

Under this Order are comprehended all the minerals which have an earthy basis combined with an acid. The minerals belonging to it are of course salts, and as such have been described in a former part of this Work: But as they occur native in states which cannot always be imitated by art, it will be necessary to take a view of them as they are found in the earth. They naturally divide themselves into five genera; as only five earths have hitherto been discovered native in combination with an acid. These genera, and the species belonging to them, are the following:

Arrangement.

I. Calcareous Salts.

1. Carbonat of lime,
2. Sulphat of lime,
3. Phosphat of lime,
4. Fluat of lime
5. Arseniat of lime.

II. Barytic Salts.

1. Carbonat of barytes,
2. Sulphat of barytes.

III. Strontian Salts.

1. Carbonat of strontian,
2. Sulphat of strontian.

IV. Magnesian Salts.

1. Sulphat of magnesia,
2. Carbonat of magnesia,
3. Borat of magnesia.

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V. Aluminous Salts.

1. Alum,
2. Mellat of alumina,
3. Fluat of alumina-and-soda.

The minerals belonging to this Order are distinguished without much difficulty from the last. Almost all of them are insoluble in water; but soluble in nitric acid or in hot sulphuric acid. Most of them melt before the blow-pipe. Their specific gravity varies; but it is often above 3.5 when the mineral is too soft to scratch glass. None of them have the metallic lustre.

Genus I. Calcareous Salts.

Pure lime.

The existence of pure uncombined lime in a native state has been questioned; but the evidence on which the belief of its existence is founded is sufficiently respectable to put the matter beyond doubt. Monnet affirms that it exists in abundance in the mountains of Upper Auvergne, mixed, however, with a little oxide of iron *. Dr Falconer of Bath found a soft whitish mineral in the neighbourhood of that town, consisting partly of pure lime capable of dissolving sulphur †, and from which lime-water may be made. I have been informed by his son Mr Thomas Falconer, that a gentleman, lately engaged in collecting the minerals about Bath found it, though not in any great quantity. But as the pure lime in these specimens is mixed with other

* Monnet's *Mineralogy*, p. 515.

† *On Bath Waters*, p. 156.

bodies, it can scarcely with propriety be considered as a distinct mineral.

Class I. Order II. Genus I.

This genus comprehends all the combinations of lime with an acid that occur in the mineral kingdom.

Sp. 1. Carbonat of lime.

No other mineral can be compared with carbonat of lime in the abundance with which it is scattered over the earth. Many mountains consist of it entirely, and hardly a country is to be found on the face of the globe where, under the names of limestone, chalk, marble, spar, it does not constitute a greater or smaller part of the mineral riches.

It is often amorphous, often stalactical, and often crystallized. The primitive form of its crystals is a parallelopiped, whose sides are rhombs, with angles of 78° 30′ and 11° 30′. Its integrant molecules have the same form. The varieties of its crystals amount to more than 50. For a description and figure of which the reader is referred to *Romé de Lisle** and *Hauy*†.

Crystals.

When crystallized, its texture is foliated; when amorphous, its texture is sometimes foliated, sometimes striated, sometimes granular, and sometimes earthy. Its lustre varies from 0 to 3. Transparency from 0 to 4. It causes double refraction; and it is the only mineral which causes double refraction through two parallel faces of the crystal. Hardness from 3 to 9. Specific gravity from 2.315 to 2.78. Colour, when pure, white.

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* *Crystallog.* i. 497.

† *Essai d'une Theorie*, &c. p. 75.—*Jour. de Phys* 1793, August, p. 11. and *Miner.* ii. 130.—*Jour. de Hist. Nat.* 1792, February, p. 148.—*Ann. de Chim.* xvii. 249, &c.—*Jour. de Min.* No. xxviii. 304.

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Effervesces violently with muriatic acid, and dissolves completely, or leaves but a small residuum. The solution is colourless.

This species occurs in a great variety of forms; and therefore has been subdivided into numerous subspecies. All these may be conveniently arranged under three general divisions.

I. Soft carbonat of lime.

Subspecies 1. Agaric mineral—*Mountain milk*, or *Mountain meal* of the Germans.

Subspecies.

This variety is found in the clefts of rocks, or the bottom of lakes. It is very brittle; stains the fingers; does not adhere to the tongue; of a white colour; sometimes with a shade of yellow; and so light that it almost floats on water.

Subspecies 2. Chalk.

The colour of chalk is white, sometimes with a shade of yellow. Lustre 0. Opaque. Hardness 3 to 4. Specific gravity from 2.315 to 2.657. Texture earthy. Adheres slightly to the tongue. Feels dry. Stains the fingers, and marks. Falls to powder in water. It generally contains about $\frac{2}{100}$ of alumina and $\frac{3}{100}$ of water; the rest is carbonat of lime.

II. Indurated carbonat of lime.

This division comprehends several minerals, which though composed of the same ingredients, as far at least as we can depend upon chemical analysis, yet do not appear to have the same structure.

Subspecies 1. Compact limestone.

Always massive. Texture compact. Fracture splintery, and sometimes conchoidal. It has little lustre. Transparency 1; rarely opaque. Hardness 5 to 8. Specific gravity 2.6 to 2.72. Brittle. Colour grey, with

various shades of other colours. It most commonly contains about $\frac{1}{10}$th of alumina, oxide of iron, &c.; the rest is carbonat of lime. Class I. Order II. Genus I.

This subspecies forms entire stratiform mountains. Very frequently it contains petrefactions; usually sea shells. Many *marbles* belong to it.

Subspecies 2. Foliated limestone.

This extensive subspecies is usually divided into two varieties.

Variety 1. Granularly foliated limestone.—Always massive. Structure sometimes slaty. Texture straight foliated and granular. Lustre 2, pearly. Transparency 2 to 1. Hardness 7 to 8. Specific gravity 2.71 to 2.8376. Brittle. Colour white, of various shades from other colours. Composed of separate parts, which are granular.—Carrara and Paros marble belongs to this variety. This variety is common, and confined exclusively to the primitive mountains. The mineral called *dolomite* belongs likewise to granularly foliated limestone. It is distinguished by the slowness with which it effervesces in acids. Varieties.

Variety 2. Calcareous spar.—This mineral occurs massive, but much more frequently crystallized. Almost all the crystals of carbonat of lime belong to it. Structure sparry. Texture foliated. Fragments rhomboidal. Lustre 2 to 3; glassy or pearly. Transparency from 2 to 4; sometimes 1. Hardness 5 to 6. Specific gravity from 2.693 to 2.718. Colour white; often with various shades of other colours.

Subspecies 3. Fibrous limestone.

This subspecies comprehends all the stalactites formed from the gradual deposition of carbonat of lime from water. Colour most frequently white; but often green, Fibrous limestone.

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yellow, brown, &c. Found in masses which assume various imitative forms. Lustre internal 1 to 2; sometimes 0. Silky. Texture straight, fibrous. Fragments cuneiform. Transparency 2 to 1. Hardness 5 to 7. Specific gravity from 2.6 to 2.77. Brittle. This subspecies is sometimes distinguished by the name of *alabaster*.

The mineral called *satin spar*, found in England, though not a stalactite, is fibrous. It ought to form a subspecies apart *.

Subspecies 4. Pisolite.

Pisolite.

This mineral has been found at Carlsbad in Bohemia. It has the form of round masses composed of concentric layers, and containing each a grain of sand in their centre. Colour white; often greyish, reddish, or yellowish. The round bodies are collected together like a bunch of grapes. Lustre 0. Transparency 0 or 1. Hardness 6 to 7. Moderately heavy.

The variety of compact limestone called *oolite*, because it resembles the spawn of fishes petrified, has been often referred to this subspecies.

Schiefers ar.

Subspecies 5. Schieferspar—*Argentine* of Kirwan.

Colour greyish, reddish, greenish, or yellowish white. Found massive. Lustre 3, pearly. Texture curve foliated. Brittle. Transparency 1, sometimes 3. Feel unctuous. May be scratched by the nail. Specific gravity 2.740. Composed of carbonat of lime, with a very little silica and oxide of iron †.

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* For a description and analysis of this mineral, the reader is referred to Mr Pepys, *Phil. Mag.* xii. 365.

† See the analysis of Mr Philips, and the description of Mr Aiken, Ibid. xiv. 289.

Subspecies 6. Arragonite.

Class I. Order II. Genus I. Arragonite.

This mineral was first found in Arragon; afterwards in the Pyrenees and at Salzburg. Colour greyish or greenish white; in the middle often violet or reddish brown. Always crystallized in regular six-sided prisms; or having two opposite faces larger. Longitudinally striated. Lustre 2, glassy. Texture foliated. Clivage double; one parallel to the axis, another forming with the first an angle of $116\frac{1}{2}°$. Formed of small scapiform pieces, which give it a granulated appearance. Scratches calcareous spar. Brittle. Specific gravity 2.9468. Constituents, as determined by Klaproth, Vauquelin, and Thenard, lime and carbonic acid in the usual proportions. This is the only anomaly which has hitherto occurred in Hauy's theory of crystallization. The primitive form of arragonite cannot be brought to that of calcareous spar, yet their constituents are the same.

III. Carbonat of lime mixed with a foreign body.

Mixtures.

The most remarkable mixtures or combinations of carbonat of lime with other bodies are the following:

1. Carbonat of lime and carbonat of magnesia—Bitterspath.

2. Carbonat of lime and oxide of iron—Brownspar.

3. Carbonat of lime and hydrosulphuret of lime—Swinestone.

4. Madreporite.

5. Carbonat of lime and sand—Crystallized sandstone of Fontainbleau.

6. Carbonat of lime and clay—Marl.

7. Marl and bitumen—Bituminous marl.

Some of these minerals may be chemical combinations; but in most the foreign bodies are merely mechanically mixed with the carbonat of lime; accord-

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ingly that substance preserves its usual crystalline form.

Bitterspath.

Subspecies 1. Bitterspath—*Muricalcite* of Kirwan.

This mineral occurs in Germany and Sweden; sometimes massive; sometimes crystallized in rhombs, similar to those of carbonat of lime. Lustre external 2, 1; internal 3 to 4, glassy. Texture lamellar. Fragments rhomboidal. Transparency 1, sometimes 2. Streak white. Brittle. Specific gravity 2.480. Scratches calcareous spar. Colour various shades of grey and yellow. Before the blow-pipe it becomes brown. Scarcely effervesces in nitric acid. According to Klaproth, its constituents are,

Composition.

From Tirol,	From Sweden,	
52	73	carbonat of lime
45	25	carbonat of magnesia
3	2¼	oxides of iron and manganese
100	100.25 *	

Subspecies 2. Brownspar—*Spath perlé.*

Brownspar.

This mineral is found commonly in Germany, Sweden, France, &c. Sometimes massive; but often crystallized. Crystals have the figures of carbonat of lime. Lustre 2, 3, seldom 4; internal 2, 3, pearly. Texture curve foliated. Separate pieces granular. Transparency 1. Scratches calcareous spar. Brittle. Specific gravity 2.837. Effervesces slowly in acids. Colour white, with various shades of grey, yellow, red. Constituents, according to Bergman,

* Beitrage, i. 304.

50 carbonat of lime
22 oxide of iron
28 oxide of manganese

100

Composition.

Subspecies 3. Swinestone.

Texture often earthy. Fracture often splintery. Lustre 1 to 0. Transparency 0 to 1. Hardness 6 to 7. Specific gravity 2.701 to 2.7121. Colour grey, of various shades. When scraped or pounded, it emits an urinous or garlic smell.

Subspecies 4. Madreporite.

Madreporite.

This mineral has been found in the valley of Russbach in Salzburg; and it got its name from its resemblance to madrepore. Colour in some parts black; in others ash grey. Found in large round masses. Composed of separate pieces scapiform; sometimes parallel, sometimes diverging. Fracture even, passing to the conchoidal. Lustre greasy, passing to the silky. Hardness 7 to 8. Brittle. Moderately heavy. Streak grey. According to Klaproth, it is composed of

Composition.

93.00 carbonat of lime
0.50 carbonat of magnesia
1.25 carbonat of iron
0.50 charcoal
4.50 silica in sand

99.75 *

Subspecies 5. Crystallized sandstone of Fontainbleau.

In the sandstone quarries at Fontainbleau occur large clusters of crystals consisting of rhomboids, the inverse

* Beitrage, iii. 276.

of the primitive form of calcareous spar. They have the appearance of a sandstone, and are now known to be crystals of carbonat of lime, which have enveloped while crystallizing a quantity of siliceous sand, at least equal to that of the carbonat, to which the crystal owes its form.

Subspecies 6. Marl.

Marl. A mixture of carbonat of lime and clay, in which the carbonat considerably exceeds the other ingredient, is called *marl*. Its texture is earthy. Lustre 0. Opaque. Hardness from 4 to 8; sometimes in powder. Specific gravity from 1.6 to 2.877. Colour usually grey, often tinged with other colours. Effervesces with acids. Some marls crumble into powder when exposed to the air; others retain their hardness for many years. Marls may be divided into two varieties: 1. Those which contain more silica than alumina; 2. Those which contain more alumina than silica. Mr Kirwan has called the first of these *siliceous*, the second *argillaceous* marls. Attention should be paid to this distinction when marls are used as a manure.

Subspecies 7. Bituminous marl.

Found in different parts of Germany. Colour greyish or brownish black. Found massive. Shistose. Plates flat or waved. Lustre of the fracture 0 or 1. Opaque. Hardness 4. Feels soft. Easily broken. Moderately heavy. Effervesces with acids. Burns before the blow-pipe, leaving black scoriæ.

Sp. 2. Sulphat of lime*.

This mineral occurs abundantly in different parts of

* Brochant, i. 600.—Hauy, ii. 266.

Class I. Order II. Genus I.

the world, forming strata and likewise veins. It is frequently massive, but it occurs also crystallized. The primitive form of its crystals is a four sided prism, whose bases are oblique parallelograms, with angles of 113° 7′ 48″ and 66° 52′ 12″. It occurs crystallized in six-sided prisms, terminated by two-sided or four-sided summits. For a description and figure of its varieties, the reader is referred to *Romé de Lisle** and *Hauy*†.

Crystals.

The texture of sulphat of lime is most commonly compact or foliated. Lustre from 0 to 4. Transparency from 0 to 4. It causes double refraction. Its hardness does not exceed 4. Specific gravity from 1.872 to 2.311. Colour commonly white or grey. Before the blow-pipe it melts into a white enamel, provided the blue flame be made to play upon the edges of its laminæ. When the flame is directed against its faces, the mineral falls into powder‡. It does not effervesce with muriatic acid except it be impure, and the acid does not dissolve it. It is usually divided into four subspecies.

Subspecies 1. Earthy gypsum.

Subspecies.

Of the consistence of meal. Lustre 0. Opaque. Scarcely sinks in water. Is not gritty between the teeth. Feels dry and meagre. Colour white. When heated below redness, it becomes of a dazzling white.

Subspecies 2. Compact gypsum.

Found massive. Texture compact. Lustre 1 or 0. Transparency 2 to 1. Hardness 4. Specific gravity about 2.3. Feels dry, but not harsh. Colour white,

* *Crystallog.* i. 144. † *Miner.* ii. 270.

‡ Le Lievre, *Jour. de Min.* No. xxviii. 315

often with a shade of grey, or yellow; sometimes yellow; sometimes red; sometimes spotted, striped, or veined. This subspecies is often distinguished by the name of alo-baster.

Subspecies 3. Fibrous gypsum.

Found massive. Texture fibrous. Fragments long splintery. Lustre 2 to 3. Transparency 2 to 1; sometimes 3. Hardness 4. Brittle. Specific gravity 2.300. Colour white, often with a shade of grey, yellow, or red; sometimes flesh red, and sometimes honey yellow; sometimes several of these colours meet in stripes.

Subspecies 4. Foliated gypsum.—*Selenite.*

Occurs massive, and likewise crystallized. Colour white; often with a shade of grey, yellow, red. Internal lustre 2 to 4. Pearly. Texture foliated. Fragments rhomboidal; sometimes indeterminate. Transparency 3 to 4. Hardness 4. Feels soft. Specific gravity from 2.274 to 2.310.

Sp. 3. Phospat of lime.

Apatite—Phosphorite—Chrysolite of the French.—*Spargelstein.*

This substance is found in Spain, where it forms whole mountains, in different parts of Germany, and in Cornwall It is sometimes amorphous, and sometimes crystallized. The primitive form of its crystals is a regular six-sided prism. Its integrant molecule is a regular triangular prism, whose height is to a side of its base as 1 to $\sqrt{2}$ * Sometimes the edges of the primitive hexagonal prism are wanting, and small faces in

Crystals.

* Hauy, *Jour. de Min.* No. xxviii. 310.

their place; sometimes there are small faces instead of the edges which terminate the prism; sometimes these two varieties are united; sometimes the terminating edges and the angles of the prism are replaced by small faces; and sometimes the prism is terminated by four sided pyramids*. This mineral is usually divided into two subspecies.

Subspecies 1. Common apatite.

Apatite.

Colour green, blue, red, brown, grey. Almost always crystallized. Its texture is foliated. Its fracture uneven, tending to conchoidal. External lustre from 2 to 3; internal, 3 to 2. Transparency from 4 to 2. Causes single refraction. Hardness 6 to 7. Brittle. Specific gravity from 2.8249 to 3.218. It is infusible by the blow-pipe. When its powder is thrown upon burning coals, it emits a yellowish green phosphorescent light, except the variety called spargelstein. It is soluble in muriatic acid without effervescence or decomposition, and the solution often becomes gelatinous. This mineral occurs in different parts of Germany and Spain. Its composition was first ascertained by Klaproth.

Subspecies 2. Earthy apatite.

This mineral was first observed in Spain, where it forms whole mountains. Colour yellowish, and greyish white. Found massive. Lustre 0. Texture earthy. Fragments indeterminate. Opaque. Hardness 7, often friable. Easily broken. Specific gravity 2.824. Its composition was first ascertained by Proust.

* Hauy, *Jour. de Min.* No. xxviii. 210.

Sp. 4. Fluat of Lime.—*fluor spar.*

This mineral is found abundantly in different countries, particularly in Derbyshire. It is both amorphous and crystallized.

Crystals.

The primitive form of its crystals is the regular octahedron; that of its integrant molecules the regular tetrahedron *. The varieties of its crystals hitherto observed amount to 9. These are the primitive octahedron; the cube; the rhomboidal dodecahedron; the cubo-octahedron, which has both the faces of the cube and of the octahedron; the octahedron wanting the edges; the cube wanting the edges, and either one face, or two faces in place of each. For a description and figure of these, the reader is referred to Mr Hauy †.

Werner divides this species into three subspecies.

Subspecies 1. Earthy.

Subspecies.

Colour greenish white or bluish green. Composed of earthy powder, somewhat agglutinated. Lustre 0. Stains somewhat. Feel harsh. Moderately heavy. Phosphoresces on hot coals. Found in Hungary in a vein. According to Pelletier, it is composed of

21 lime
15 alumina
31 silica
28 fluoric acid
1 phosphoric acid
1 muriatic acid
1 oxide of iron
1 water

99

* Hauy, *Jour. de Min.* No. xxviii. 325. † Ibid. and *Min.* ii. 248.

Subspecies 2.—Compact fluor.

Colour greenish grey, often spotted. Found in mass. Internal lustre 0, 1. Greasy. Fracture even, passing to the conchoidal. Transparency 2. Scratches calcareous spar. Moderately heavy.

Subspecies 3. Fluor spar.

The texture of fluat of lime is foliated. Lustre from 2 to 3. Transparency from 2 to 4, sometimes 1. Causes single refraction. Hardness 8. Very brittle. Specific gravity from 3.0943 to 3.1911. Colours numerous, red, violet, green, reddish yellow, blackish purple. Its powder thrown upon hot coals emits a bluish or greenish light. Two pieces of it rubbed in the dark phosphoresce. It decrepitates when heated. Before the blow-pipe it melts into a transparent glass *.

It admits of a polish, and is often formed into vases and other ornaments.

Sp. 5. Arseniat of lime †.

Pharmacolite of Kärsten.

Found near Wittichen in Suabia in tubercles or small capillary crystals united in bundles. Colour snow white. Lustre internal 1, 2, silky. Texture fibrous; fibres diverging. Transparency of the crystals 4. Very friable. Specific gravity 2.64 to 2.536. Klaproth found it composed of

* Hauy, *Jour de Min.* No. xxviii. 325.

† Hauy, ii. 293.—Brochant, ii. 523.

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Composition.

46.50 arsenic acid
23.00 lime
0.50 oxide of cobalt
6.00 clay
22.50 water

98.50

or abstracting the impurities of

50.84 arsenic acid
25.00 lime
24.46 water

100.00 *

Sp. 6. Nitrat of lime.

Found abundantly mixed with native nitre. For a description see Volume II. p. 416.

Genus II. Barytic Salts.

This genus comprehends the combinations of barytes with acids.

Sp. 1. Carbonat of barytes †.

Witherite.

This mineral was discovered by Dr Withering; hence Werner has given it the name of *Witherite*. It is found both amorphous and crystallized, chiefly at Anglesark in Lancashire. The crystals are very small and rare. Hence their primitive form has not been ascertained.

Crystals.

* *Beitrage*, iii 281. † Brochant, i. 612.—Hauy, ii. 308.

Class I. Order II. Genus II.

They are six-sided prisms, terminated by six-sided pyramids, or double six-sided pyramids. Colour yellowish grey. Fracture, in one sense, intermediate between foliated and radiated; cross fracture, uneven. Fragments wedge-shaped. Lustre 2. Transparency 2 to 3. Hardness 5 to 6. Brittle. Specific gravity 4.3 to 4.338. Colour greenish white. When heated it becomes opaque. Its powder phosphoresces when thrown on burning coals *.

It is soluble with effervescence in muriatic acid. The solution is colourless.

Composition.

According to Pelletier it contains

62 barytes
22 carbonic acid
16 water

100 †

But Klaproth found it composed of

98.246 carbonat of barytes
1.703 carbonat of strontian
0.043 alumina with iron
0.008 carbonat of copper

100.000 ‡

Sp. 2. Sulphat of barytes §

Baroselenite.

This mineral is found abundantly in many countries, particularly in Britain. It is sometimes in powder, oft-

* Hauy. † *Jour. de Min.* xxi. 46. ‡ *Beitrage*, ii. 86.
§ Brochant, i. 617.—Hauy, ii. 295.

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en in amorphous masses, and often crystallized. The primitive form of its crystals is a rectangular prism, whose bases are rhombs, with angles of 101° 30′ and 78° 30′ *. The varieties of its crystals amount to 14. For a description and figure of them I refer to Romé de Lisle † and Hauy ‡. The most common varieties are the octahedron with cuneiform summits, the six or four sided prism, the hexangular table with bevelled edges. Sometimes the crystals are needleform.

Properties.

Lustre from 0 to 2. Transparency from 2 to 0; in some cases 3 or 4. Hardness from 5 to 6. Specific gravity from 4.4 to 4.44. Colour commonly white, with a shade of yellow, red, blue, or brown. When heated it decrepitates. It is fusible *per se* by the blue flame of the blow-pipe, and is converted into sulphuret of barytes. Soluble in no acid except the sulphuric; and precipitated from it by water. Werner divides this species into seven subspecies.

Subspecies 1. Earthy sulphat.

Subspecies.

In the form of coarse dusty particles, slightly cohering. Colour snow white, greyish, reddish, or yellowish white. Does not stain. Uncommon. Found incrusting the other subspecies.

Subspecies 2. Compact sulphat.

Texture compact, earthy. Lustre 0 to 1. Transparency 0 to 1. Feels meagre. Almost constantly impure. Colours light yellow, red, grey. Found massive.

Subspecies 3. Granular sulphat.

Colour snow white; sometimes greyish, yellowish,

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* Hauy, *Essai d'une Theorie*, p. 119. † *Crystal.* i. 588.

‡ Ibid. and *Ann. de Chim.* xii. 3. and *Miner.* ii. 298.

reddish. Found in mass. Lustre 1 to 2, pearly. Fracture small, foliated, passing to splintery. Separate pieces granular. Transparency 2. Brittle. Specific gravity 3.8. Bears some resemblance to granular limestone.

Subspecies 4. Curve-foliated sulphat.

Colour yellowish, reddish, or greyish white. Found in mass or in round pieces; sometimes in the form of tables. Their surface usually drusy. Lustre external 1 to 2, pearly. Fracture curve-foliated; sometimes passing into the splintery. Separate pieces in thick curve plates longitudinally striated. Transparency 1 to 2. Very soft. Brittle.

Subspecies 5. Straight foliated sulphat.

Colour white; often red, brown, yellow, green, grey. Found massive, and often crystallized. To this subspecies belong most of the crystallized specimens of sulphat of barytes. Lustre 3 to 0, pearly. Fracture straight foliated. Clivage triple. Fragments rhomboidal. Separate pieces often in flat plates. Transparency from 4 to 2. Soft. Brittle. Specific gravity 4·3 to 4·5

Subspecies 6. Stangenspath, or sulphat in bars.

Colour white; sometimes grey, red, or green. Always crystallized. The crystals are four-sided prisms terminated by two sided or four-sided summits, or six-sided prisms terminated by two-sided summits. Crystals very long and small, united in clusters. Lustre 3 to 2. Longitudinal fracture radiated; cross fracture even. Transparency 2. Soft. Brittle.

Subspecies 7. Bologna stone.

Colour grey. Found in round masses. Lustre external 0 to 1; internal 3 to 2, pearly. Fracture radi-

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ated. Fragments splintery or indeterminate. Transparency 2. Specific gravity from 4.44 to 4.496.

Genus III. Strontian Salts.

This genus comprehends all the combinations of strontian and acids which form a part of the mineral kingdom.

Sp. 1. Carbonat of strontian.

This mineral was first discovered in the lead mine of Strontian in Argyleshire; and since that time it is said to have been discovered, though not in great abundance, in other countries. It is found amorphous and also crystallized in needles, which, according to Hauy, are regular six-sided prisms.

Properties.

Its texture is radiated; the rays converge. Fracture uneven. Lustre 2. Transparency 2. Hardness 5. Specific gravity from 3.4 to 3.66. Colour light green. Does not decrepitate when heated. Before the blowpipe becomes opaque and white, but does not melt. With borax it effervesces, and melts into a transparent colourless glass. Effervesces with muriatic acid, and is totally dissolved. The solution tinges flame purple.

Sp. 2. Sulphat of strontian.

Celestine.

This mineral has been found in Pennsylvania, in Germany, in France, in Sicily, and Britain. It was first discovered near Bristol by Mr Clayfield. There it is found in such abundance, that it has been employed in mending the roads. It occurs often massive, but frequently crystallized. The primitive form of its crys-

Crystals.

Class II.
Order II.
Genus I I.

tals is a four-sided prism, whose bases are rhombs with angles of 104° 48′ and 75° 12′. The varieties of its crystals, as described by Hauy, amount to seven *. They may be referred to four or six sided prisms, terminated by two, four, or eight sided summits. Scratches calcareous spar, is scratched by fluor spar. Specific gravity from 3.5827 to 3.9581. Causes a double refraction. It may be divided into three subspecies †.

Subspecies 1. Earthy sulphat of strontian.

Subspecies.

This mineral is found in Montmartre near Paris. Colour bluish grey. Found massive in round pieces. Lustre 0. Fracture compact, and somewhat splintery. Opaque. Brittle. Specific gravity 3.5. Contains, according to Vauquelin, 91.42 sulphat of strontian

8.33 carbonat of lime

0.25 oxide of iron

100.00

Subspecies 2. Fibrous sulphat of strontian.

Colour pale blue; sometimes reddish; sometimes white. Found in mass. Lustre external 0 to 1; internal 2 to 3, intermediate between glassy and greasy. Fracture fibrous; fibres straight. Somewhat transparent. Specific gravity 3.83. Most common.

Subspecies 3. Foliated sulphat of strontian.

Colour white. Found massive and in crystals. Crystals grouped. The amorphous specimens fibrous; fibres diverging. Lustre of the crystals 3 to 4. Their

* *Miner.* ii. 315.

† Brochant, i. 642.

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texture straight foliated. Transparency 2 to 4. Found in Sicily and in Britain.

A great many curious varieties of this mineral have been found in the south-west of England.

Genus IV. Magnesian Salts.

Sp. 1. Borat of Magnesia. *Boracite.*

Crystals.

This mineral has been found at Kalkberg near Luneburg, seated in a bed of sulphat of lime. It is crystallized. The primitive form of its crystals is the cube*. In general, all the edges and angles of the cube are truncated; sometimes, however, only the alternate angles are truncated†. The size of the crystals does not exceed half an inch.

Properties.

The texture of this mineral is compact. Its fracture is flat conchoidal. External lustre 3; internal, greasy, 2. Transparency from 2 to 3. Hardness 9 to 10. Specific gravity 2.566. Colour greyish white, sometimes passing into greenish white or purplish. When heated it becomes electric; and the angles of the cube are alternately positive and negative‡. Before the blowpipe it froths, emits a greenish light, and is converted into a yellowish enamel, garnished with small points, which, if the heat be continued, dart out in sparks §.

* Hauy, *Jour. de Min.* No. xxviii. 325.
† Hauy and Westrum.
‡ Hauy, Ibid. and *Ann. de Chim.* ix. 59.
§ Le Lievre, *Jour. de Min.* Ibid.

Sp. 2. Sulphat of Magnesia.

This salt is frequently found effloresced on the surface of rocks, walls, &c. in different parts of the world. Klaproth has shewn that the substance from Idria, distinguished by the Germans by the name of *Haarsalz*, is sulphat of magnesia nearly pure*.

Sp. 3. Nitrat of Magnesia.

This salt is found in different countries, either sparingly mixed with the soil, or effloresing upon walls, or dissolves in mineral waters. I have mentioned it merely in compliance with the custom of mineralogists; for it ought not, strictly speaking, to be ranked among minerals.

Genus V. Aluminous Salts.

This genus comprehends all the combinations of alumina with acids, which constitute a part of the mineral kingdom. Hitherto only three species have occurred.

Sp. 1. Alum.

This salt is found in crystals, in soft masses, in flakes, and invisibly mixed with the soil. For a description, I refer to Vol. II. p. 364.

* Beitrage, iii. 104.

Sp 2. Mellite*.

Honeystone—Mellat of Alumina.

This mineral was first observed about ten years ago in Thuringia, between the layers of wood coal. It is of a honey-yellow colour (hence its name), and is usu-
Properties. ally crystallized in small octahedrons, whose angles are often truncated. Lustre 2 to 3. Transparency considerable. Fracture conchoidal. Hardness 5. Specific gravity, according to Abich, 1.666. When heated it whitens; and in the open air burns without being sensibly charred. A white matter remains, which effervesces slightly with acids, and which at first has no taste, but at length leaves an acid impression upon the tongue.

Sp. 3. Chriolite†.

Fluat of Soda-and-alumina.

This mineral has hitherto been found in Greenland only; from which it was brought to Copenhagen, where it lay eight or nine years unnoticed, till at last it was
Properties analysed by Abelgaard. The primitive form of its crystals seems to be an octahedron, whose faces are isosceles triangles. Its colour is snow white. Texture foliated. Hardness inferior to that of fluat of lime. Specific gravity 2.949. Melts before it reaches a red

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* Emmerling's *Lehrbuch*, ii. 89.—Wiedeman's *Handbuch*, p. 639.—Abich, Crell's *Annals*, 1797, ii. 3.—Vauquelin, *Ann. de Chim.* xxxvi. 23.—Klaproth, *Beitrage*, iii. 115.—Kirwan's *Min.* ii 68.—Karsten, *Mus. Leck.* ii. 335.—Brochant, ii. 73.

† *Ann. de Chim.* xxxvii. 87. and 89.—*Jour. de Phys.* lii. 35.—Hauy, Ibid. xlix. 463.

heat, and when simply exposed to the flame of a candle*. Abelgaard analysed it, and obtained fluoric acid and alumina. Klaproth has lately proved that it contains also soda. The result of his analysis is as follows:

Class II. Order II. Genus V.

Composition.

40.5	fluoric acid and water
36.0	soda
23.5	alumina
100.0	

This analysis has been confirmed by Vauquelin.

* Hence its name from χρυος and λιθος, as if it melted as easily as ice.

END OF THE THIRD VOLUME.

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Fig. 19.

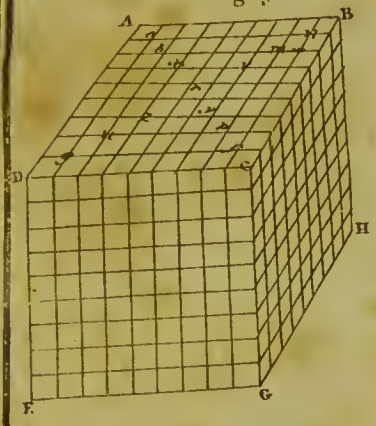


Fig. 20.

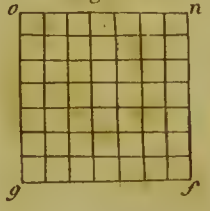


Fig. 21.



Fig. 22.

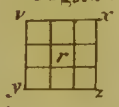


Fig. 23.



Fig. 24.

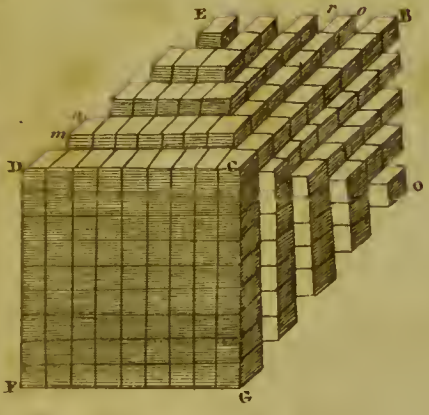


Fig. 25.

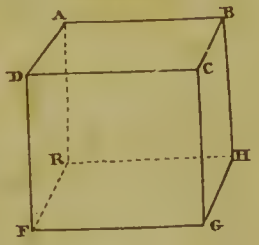


Fig. 26.

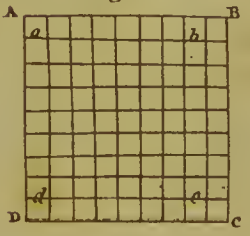


Fig. 27.

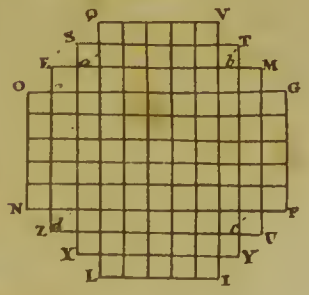


Fig. 28.

